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Initial elastic and frictional behavior of metal interfaces.

Williamson, Leslie J.

Monterey, California : Naval Postgraduate School

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**INITIAL ELASTIC AND FRICTIONAL
BEHAVIOR OF METAL INTERFACES**

Leslie J. Williamson

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39, Massachusetts

May 23, 1955

Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the regulations of the Faculty,
I submit herewith a thesis entitled "Initial Elastic
and Frictional Behavior of Metal Interfaces," in partial
fulfillment of the requirements for the degree of Master
of Science (without specification).

Respectfully yours,

Leslie J. Williamson
Lieutenant, U.S. Coast Guard

RESEARCH INSTITUTE IN TECHNOLOGY

Cambridge 32, Massachusetts

May 17, 1957

Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the regulations of the Faculty,

I submit herewith a final revised doctoral thesis

and "Final Report on the Research of the Doctoral Candidate," in partial

fulfillment of the requirements for the degree of Master

of Science (Doctoral Dissertation).

Respectfully yours,

Leslie A. Williamson

Department of Chemistry, U.S. Coast Guard

INITIAL ELASTIC AND FRICTIONAL
BEHAVIOR OF METAL INTERFACES

by

LESLIE J. WILLIAMSON
Lieutenant, U.S. Coast Guard
B.S., U.S. Coast Guard Academy
(1945)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
(without specification)

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(1955)

Signature of Author
Department of Naval Architecture and
Marine Engineering, May 23, 1955

Certified by
Thesis Supervisor

Accepted by
Chairman, Departmental Committee on Graduate Students

W626

INITIAL BLASTING AND EXPLOSIVES
RESEARCH OF METAL INDUSTRIES

LESLIE J. WILLIAMS
Lieutenant, U.S. Coast Guard
E.S., U.S. Coast Guard Academy
(1933)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTERS OF SCIENCE
(without specialization)

at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(1933)

Signature of student
Department of Naval Architecture and
Naval Engineering, May 23, 1933

Certified by
Thesis Supervisor

Accepted by
Committee on Graduate Studies

INITIAL ELASTIC AND FRICTIONAL
BEHAVIOR OF METAL INTERFACES

Leslie J. Williamson

Lieutenant, U.S. Coast Guard

Submitted to the Department of Naval Architecture
and Marine Engineering on May 23, 1955, in partial
fulfillment of the requirements for the degree of
Master of Science

ABSTRACT

The object of this thesis is to investigate the reported existence of abnormal elastic effects in metal interfaces. In conjunction with this work, the initial frictional behavior at the metal interfaces was observed.

The method of investigation selected employed hollow cylindrical specimens composed of two mating parts placed end on end. The experimental apparatus utilized a combination of optical and mechanical means of measuring small angles of twist in the specimen. Various metals were tested under different conditions of normal load and surface finish.

Excellent conformity between observed values of twist and those predicted by elastic theory was achieved. The experimental results did not show any indication of excessive elastic angles of twist.

Investigation of the initial frictional behavior of the metal interfaces indicated that the value of the friction coefficient increased with incremental changes in the observed slip until the range of normally expected values was attained. In this range the curve flattened out and free sliding resulted.

In view of the results of this investigation, it is believed that the reported abnormal elastic conditions were the result of inaccuracies in the experimental method, and that further investigation along this line is not warranted.

Thesis Supervisor: Brandon G. Rightmire

Title: Associate Professor

INITIAL CLASSIC AND INVESTIGATIVE
STUDYING TO SOCIAL INVESTIGATIVE

James E. Williams
Investment, 611, Cedar Street

Investigation to the Department of Social Investigation
and Social Investigation to the Department of Social Investigation
Investigation to the Department of Social Investigation
Investigation to the Department of Social Investigation

INITIAL

The object of this study is to investigate the various
aspects of the social investigation in the field of
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of the social investigation and observation.

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various aspects of the social investigation in the field of
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and Social Investigation to the Department of Social Investigation

ACKNOWLEDGMENT

To Professor Brandon G. Rightmire, who kindly consented to supervise this thesis, I wish to express my sincere appreciation of his helpful suggestions and encouragement during the course of the research.

I wish also to thank the members of the Lubrication Laboratory for their co-operation.

Finally, to Bertha Hornby, who typed the thesis, go my thanks for her careful work.

MEMORANDUM

TO: Professor Richard B. Lippman

FROM: [illegible]

SUBJECT: [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

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I. INTRODUCTION

In a thesis,⁽¹⁾ Coyle and Stromberg reported the existence of abnormal elastic effects in metal interfaces. As a result of their work, they concluded that the asperities in steel interfaces contribute materially to the elastic twist. The elastic twist due to an interface appeared to decrease with increase in normal stress for a given value of maximum tangential stress. They also found that the effect of surface finish was affected by normal stress, in that a transition range existed for normal stress. This transition range separated the regions where elastic twist increased or decreased with the degree of surface finish. This appears to be a virgin investigation of elastic effects in metal interfaces, as a survey of the literature failed to disclose any previous work along this line.

Tomlinson, Thorpe, and Gough,⁽²⁾ in a paper on fretting corrosion, reported that surfaces in contact under normal and tangential stresses have a comparatively high degree of tangential elasticity. "The surfaces appeared to yield under tangential stress in an elastic manner by an amount which may be many times greater than the smallest slip it is hoped to detect." This made their problem of measuring slip extremely difficult. In the second phase of this investigation, this problem was encountered where the displacements measured were of the same order of magnitude as the depth of the asperities

in the metal interfaces. The first objective of this investigation was the development of a test apparatus and an experimental procedure of sufficient sensitivity and accuracy so that the existing discrepancies between calculated theoretical and observed values of elastic twist would be eliminated or rationalized. Various methods of measuring elastic twist in a specimen were considered, as discussed in Appendix A.

The second phase of this work was a by-product of the original investigation. After extensive examination of the elastic effects at metal interfaces under various conditions of load and surface finish, it was decided that a study of the frictional behavior would be both interesting and valuable.

in the next instance. The first objective of this investigation was the development of a test apparatus and an experimental procedure to establish sensitivity and accuracy in measuring the relationship between selected physical and chemical properties of various soils. Various methods of measuring physical properties were considered, as discussed in Appendix I.

The second phase of this work was a by-product of the physical investigation. After extensive consideration of the physical effects of soil, interest was aroused in the possibility of using the physical effects as a means of determining soil properties. It was decided that a study of the physical properties would be both interesting and valuable.

The third phase of this work was a by-product of the physical investigation. After extensive consideration of the physical effects of soil, interest was aroused in the possibility of using the physical effects as a means of determining soil properties. It was decided that a study of the physical properties would be both interesting and valuable.

The fourth phase of this work was a by-product of the physical investigation. After extensive consideration of the physical effects of soil, interest was aroused in the possibility of using the physical effects as a means of determining soil properties. It was decided that a study of the physical properties would be both interesting and valuable.

II. PROCEDURE

The test apparatus used in this work is illustrated in Figures I, II, and III.

The tubular specimens tested were machined from the following materials: (1) AISI C-1018, cold-finished, open-hearth, low-carbon steel; (2) AISI A-4140, heat-treated, stress-relieved, medium-carbon alloy steel; (3) hard-drawn, electrolytic, tough pitch copper rod; (4) 2S Aluminum.

The specimens were reamed out to an inside diameter of 0.191"; then turned down to 0.236" outside diameter. The test specimens were cut into two halves, each one inch long. A single two-inch specimen was made for each material, and used as a control specimen. The observed deflections of the control specimen (ψ_c) were compared with the computed deflections (ψ_e) as predicted by elastic theory, thus providing a check of the accuracy of the test runs. The effect of the interface could be determined by a comparison of control-specimen runs with test-specimen results.

The upper and lower halves of the test specimen are mounted as shown in Figure III. The contact surfaces were lapped to the desired finish with emery polishing paper of varying degrees of roughness. The specimen was clamped in a vee-type block during the polishing process, to insure that the test surfaces were ground perpendicular to the specimen axis. The specimens were carefully cleaned both before and after the

The first observation was in this work at 1100/60 Hz.

The Federal Government is not authorized to

Refined and polished (1) and (2) are the same.

Very truly yours,
John F. Kennedy

(Signature)

1970-1971, 1972-1973, 1974-1975, 1976-1977, 1978-1979, 1980-1981, 1982-1983, 1984-1985, 1986-1987, 1988-1989, 1990-1991, 1992-1993, 1994-1995, 1996-1997, 1998-1999, 2000-2001, 2002-2003, 2004-2005, 2006-2007, 2008-2009, 2010-2011, 2012-2013, 2014-2015, 2016-2017, 2018-2019, 2020-2021, 2022-2023, 2024-2025, 2026-2027, 2028-2029, 2030-2031, 2032-2033, 2034-2035, 2036-2037, 2038-2039, 2040-2041, 2042-2043, 2044-2045, 2046-2047, 2048-2049, 2050-2051, 2052-2053, 2054-2055, 2056-2057, 2058-2059, 2060-2061, 2062-2063, 2064-2065, 2066-2067, 2068-2069, 2070-2071, 2072-2073, 2074-2075, 2076-2077, 2078-2079, 2080-2081, 2082-2083, 2084-2085, 2086-2087, 2088-2089, 2090-2091, 2092-2093, 2094-2095, 2096-2097, 2098-2099, 2100-2101, 2102-2103, 2104-2105, 2106-2107, 2108-2109, 2110-2111, 2112-2113, 2114-2115, 2116-2117, 2118-2119, 2120-2121, 2122-2123, 2124-2125, 2126-2127, 2128-2129, 2130-2131, 2132-2133, 2134-2135, 2136-2137, 2138-2139, 2140-2141, 2142-2143, 2144-2145, 2146-2147, 2148-2149, 2150-2151, 2152-2153, 2154-2155, 2156-2157, 2158-2159, 2160-2161, 2162-2163, 2164-2165, 2166-2167, 2168-2169, 2170-2171, 2172-2173, 2174-2175, 2176-2177, 2178-2179, 2180-2181, 2182-2183, 2184-2185, 2186-2187, 2188-2189, 2190-2191, 2192-2193, 2194-2195, 2196-2197, 2198-2199, 2200-2201, 2202-2203, 2204-2205, 2206-2207, 2208-2209, 2210-2211, 2212-2213, 2214-2215, 2216-2217, 2218-2219, 2220-2221, 2222-2223, 2224-2225, 2226-2227, 2228-2229, 2230-2231, 2232-2233, 2234-2235, 2236-2237, 2238-2239, 2240-2241, 2242-2243, 2244-2245, 2246-2247, 2248-2249, 2250-2251, 2252-2253, 2254-2255, 2256-2257, 2258-2259, 2260-2261, 2262-2263, 2264-2265, 2266-2267, 2268-2269, 2270-2271, 2272-2273, 2274-2275, 2276-2277, 2278-2279, 2280-2281, 2282-2283, 2284-2285, 2286-2287, 2288-2289, 2290-2291, 2292-2293, 2294-2295, 2296-2297, 2298-2299, 2300-2301, 2302-2303, 2304-2305, 2306-2307, 2308-2309, 2310-2311, 2312-2313, 2314-2315, 2316-2317, 2318-2319, 2320-2321, 2322-2323, 2324-2325, 2326-2327, 2328-2329, 2330-2331, 2332-2333, 2334-2335, 2336-2337, 2338-2339, 2340-2341, 2342-2343, 2344-2345, 2346-2347, 2348-2349, 2350-2351, 2352-2353, 2354-2355, 2356-2357, 2358-2359, 2360-2361, 2362-2363, 2364-2365, 2366-2367, 2368-2369, 2370-2371, 2372-2373, 2374-2375, 2376-2377, 2378-2379, 2380-2381, 2382-2383, 2384-2385, 2386-2387, 2388-2389, 2390-2391, 2392-2393, 2394-2395, 2396-2397, 2398-2399, 2400-2401, 2402-2403, 2404-2405, 2406-2407, 2408-2409, 2410-2411, 2412-2413, 2414-2415, 2416-2417, 2418-2419, 2420-2421, 2422-2423, 2424-2425, 2426-2427, 2428-2429, 2430-2431, 2432-2433, 2434-2435, 2436-2437, 2438-2439, 2440-2441, 2442-2443, 2444-2445, 2446-2447, 2448-2449, 2450-2451, 2452-2453, 2454-2455, 2456-2457, 2458-2459, 2460-2461, 2462-2463, 2464-2465, 2466-2467, 2468-2469, 2470-2471, 2472-2473, 2474-2475, 2476-2477, 2478-2479, 2480-2481, 2482-2483, 2484-2485, 2486-2487, 2488-2489, 2490-2491, 2492-2493, 2494-2495, 2496-2497, 2498-2499, 2500-2501, 2502-2503, 2504-2505, 2506-2507, 2508-2509, 2510-2511, 2512-2513, 2514-2515, 2516-2517, 2518-2519, 2520-2521, 2522-2523, 2524-2525, 2526-2527, 2528-2529, 2530-2531, 2532-2533, 2534-2535, 2536-2537, 2538-2539, 2540-2541, 2542-2543, 2544-2545, 2546-2547, 2548-2549, 2550-2551, 2552-2553, 2554-2555, 2556-2557, 2558-2559, 2560-2561, 2562-2563, 2564-2565, 2566-2567, 2568-2569, 2570-2571, 2572-2573, 2574-2575, 2576-2577, 2578-2579, 2580-2581, 2582-2583, 2584-2585, 2586-2587, 2588-2589, 2590-2591, 2592-2593, 2594-2595, 2596-2597, 2598-2599, 2600-2601, 2602-2603, 2604-2605, 2606-2607, 2608-2609, 2610-2611, 2612-2613, 2614-2615, 2616-2617, 2618-2619, 2620-2621, 2622-2623, 2624-2625, 2626-2627, 2628-2629, 2630-2631, 2632-2633, 2634-2635, 2636-2637, 2638-2639, 2640-2641, 2642-2643, 2644-2645, 2646-2647, 2648-2649, 2650-2651, 2652-2653, 2654-2655, 2656-2657, 2658-2659, 2660-2661, 2662-2663, 2664-2665, 2666-2667, 2668-2669, 2670-2671, 2672-2673, 2674-2675, 2676-2677, 2678-2679, 2680-2681, 2682-2683, 2684-2685, 2686-2687, 2688-2689, 2690-2691, 2692-2693, 2694-2695, 2696-2697, 2698-2699, 2700-2701, 2702-2703, 2704-2705, 2706-2707, 2708-2709, 2710-2711, 2712-2713, 27

Electrolytic, such as sodium cyanide, LiCl, NaOH

For a complete listing of all the names and addresses of the

0-191: 1967-1968

Investment was not too heavy, and was not too

... (faint text) ...

After the 1960s, the observed behavior of the

[illegible]

from 1961 as provided by elastic theory, thus providing a

back of the history of the last year. The extent of the

Approved for release by NSA on 08-28-2013 pursuant to E.O. 13526

reaches you with last-minute results.

The river and lower halves of the last specimen are

revised as above in Figure 11. The contour method gave

[illegible]

trying to get it together. The speaker was elected in a

17-type bolts secured the rigidized members, an E-type cap was

11. If possible, the following information should be included in the specimen label:

and specimens were previously cleaned with distilled water.

polishing process. (Reagent acetone was used as cleaning solvent.)

Two double-ended indicator arms were used, one on either side of the interface. Each arm was constructed with two 12" lengths of Type 321 stainless-steel tubing having 1/8" outside diameter and 0.005" wall thickness. The indicator arms were fastened to the specimen by a collar, as shown in Figure III. The cone-pointed set screws were used to obtain a knife-edge line from which the twist was transmitted. The pin-point indentations produced on the specimen by the set screws permitted length "L" to be accurately picked off the specimen with draftmen's dividers.

The alignment jig shown in Figure III was used to insure that the face of the indicator-arm collar, hence the plane of the set screws, was perpendicular to the axis of the specimen.

The lower half of the specimen rests on a machined and polished steel plate. For initial tests on the steel specimens a machined steel block was used, as shown in Figure I (1). The remainder of the specimens were mounted on the machined steel block shown in Figure III. This block has a securing collar which permits clamping of the bottom end of the specimen. After a final cleaning of the two contact surfaces, the upper half of the specimen was placed on the lower portion, and the weight rod then run up through the annulus of the specimen. The weight release (screw jack) permits the weight pan support rod to be run up and down as desired.

Belgian women: foreign women are not a danger

The following is a list of the specimens of the genus *Phrynosoma* which have been deposited in the collection of the U. S. National Museum, Washington, D. C., and are now deposited in the collection of the U. S. National Museum, Washington, D. C.

The alignment of the spine is shown in Figure 11. The spine is shown in the sagittal plane. The spine is shown in the sagittal plane. The spine is shown in the sagittal plane.

The lower half of the specimen consists of a well-defined and polished steel plate. The upper half of the specimen is a well-defined steel plate, as shown in Figure 1 (a). The thickness of the specimen was measured on the polished steel plate shown in Figure 1 (b). This gives a thickness value of 0.001 inch at the top and 0.001 inch at the bottom.

After a final viewing of the two contact needles, the upper half of the specimen was placed on the lower portion, and the weight was then put up through the opening of the specimen. The weight released (about 1000) provided the weight was removed. The two ends of the wire were then secured.

The threaded upper end of the rod was then screwed into a circular disc, separated from the top of the specimen by a ball thrust bearing as illustrated in Figure III. This bearing was used to isolate the specimen from any torsional vibration or movement of the normal load weight pan.

The sight edges are pictured in Figure I (2) and Figure III. The two sight edges were polished with 4/0 paper so that a clean, sharp sighting surface was obtained. Alignment of the two sight edges could be obtained by loosening either one or both of the clamp screws, and moving the edges into position as desired. The upper arm sight edge strip was out wider than that on the lower arm. The distance from this edge to the center of the indicator-arm collar was measured accurately (12.33"), giving length "R". With the microscope focused sharply on this edge, the other sight edge strip was brought into focus by bending it slightly.

The torque arm was aligned so that the silk threads transmitting the forces from the torque weight pans are perpendicular to the lever in both horizontal and vertical planes. The pulleys were adjusted in both vertical and horizontal planes by moving pulley clamps on the support rods, as shown in Figure II. When alignment of the torque system was obtained, the torque arm and pulley support clamps were locked in place with their set screws.

The desired normal load was placed on the weight pan and then applied to the specimen by cranking down the weight release.

The zero reading of the indicator arms was then recorded.

The affected right side of the foot was more severely injured
a extensive area, commencing from the tip of the toes to the
ball of the foot being in this position in Figure 11. This
was due to the fact that the foot was in a position of
flexion at the moment of the blow being struck.
The right side was elevated in Figure 12 and
Figure 13. The two right sides were placed with the right
on the left, showing the position of the foot. The
right of the two right sides would be indicated by the
other one by both of the right sides, and noting the
into position as shown. The right side was placed with
up right side that on the lower side. The distance from the
edge to the center of the foot was 10 inches and 10 inches
approximately (10.75) is divided into 10. The distance
between the right side and the other side was 10 inches
between the two sides in Figure 14.
The right side was placed on the left side
approximately the distance from the right side was 10
inches to the left in both positions and vertical distance.
The right side was placed in both positions and positions
placed in position being placed on the right side. As shown
in Figure 15. When placed on the right side was placed,
the right side was placed on the right side in Figure
with the right side.

The right side was placed on the right side and
then placed on the right side by placing down the right side.
The two sides of the foot were then placed.

By adding equal weights to the two weight pans, a known torque was applied to the specimen and the resulting twist was measured on the optical micrometer. After each reading the torque was removed and the zero reading recorded.

After measuring the distance "L" between pin-point indentations in the specimen, these pits were marked so that they could be distinguished from marks made in the succeeding test.

by taking special permits to the few nights each, a small number
was assigned to the question and the remaining were left
overed of the original assignment. They were then divided into
groups and assigned to the two main sections.

After consulting the Director of the Bureau of the Census, the Bureau of the Census has advised that the Bureau of the Census has no information regarding the Bureau of the Census.

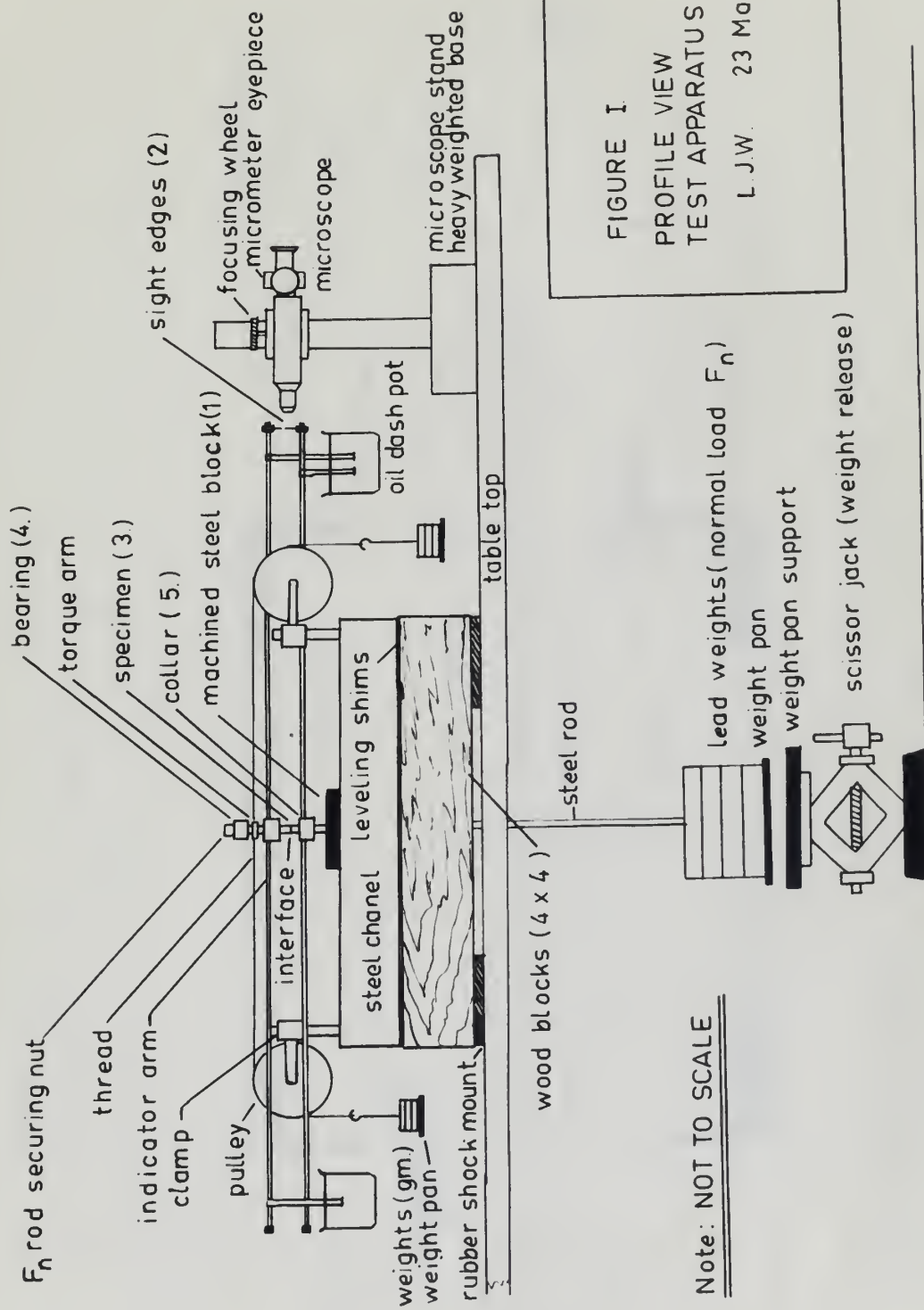
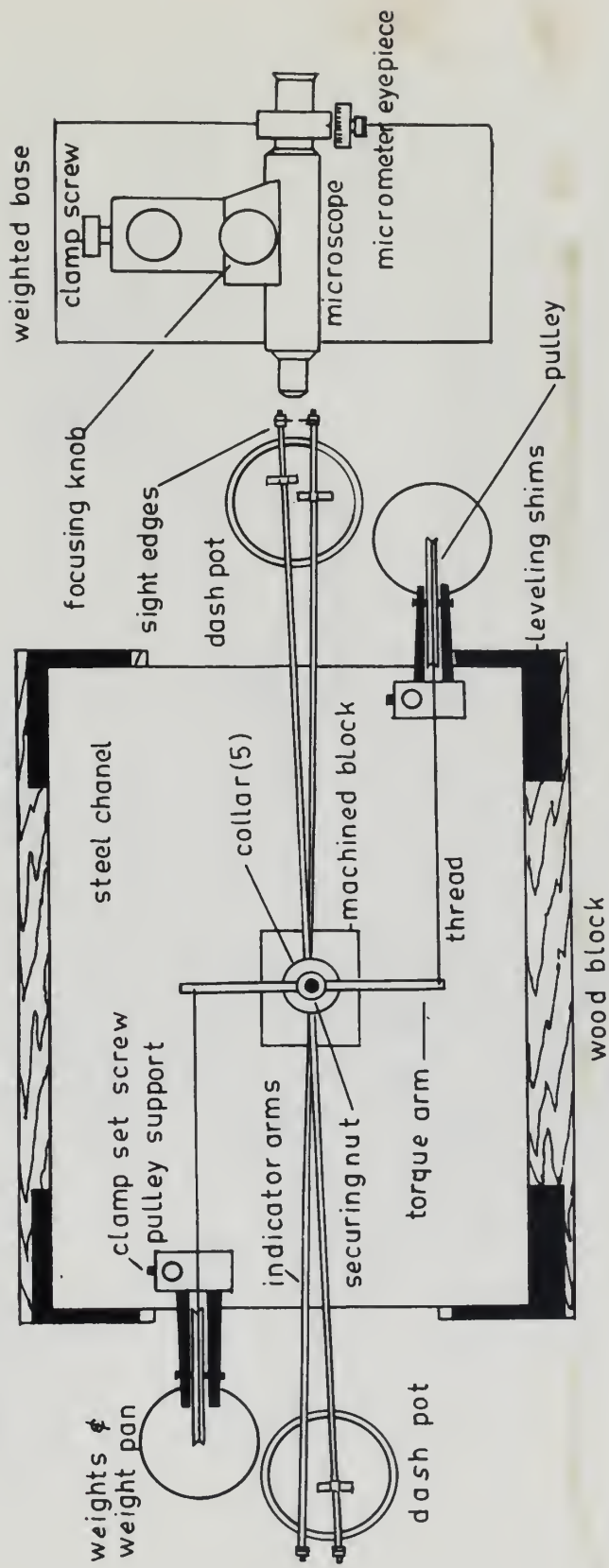


FIGURE I
PROFILE VIEW
TEST APPARATUS

L. J.W. 23 May, 1955

FIGURE II.
PLAN VIEW OF TEST APPARATUS



Note: NOT TO SCALE

L.J.W. 23 May, 1955

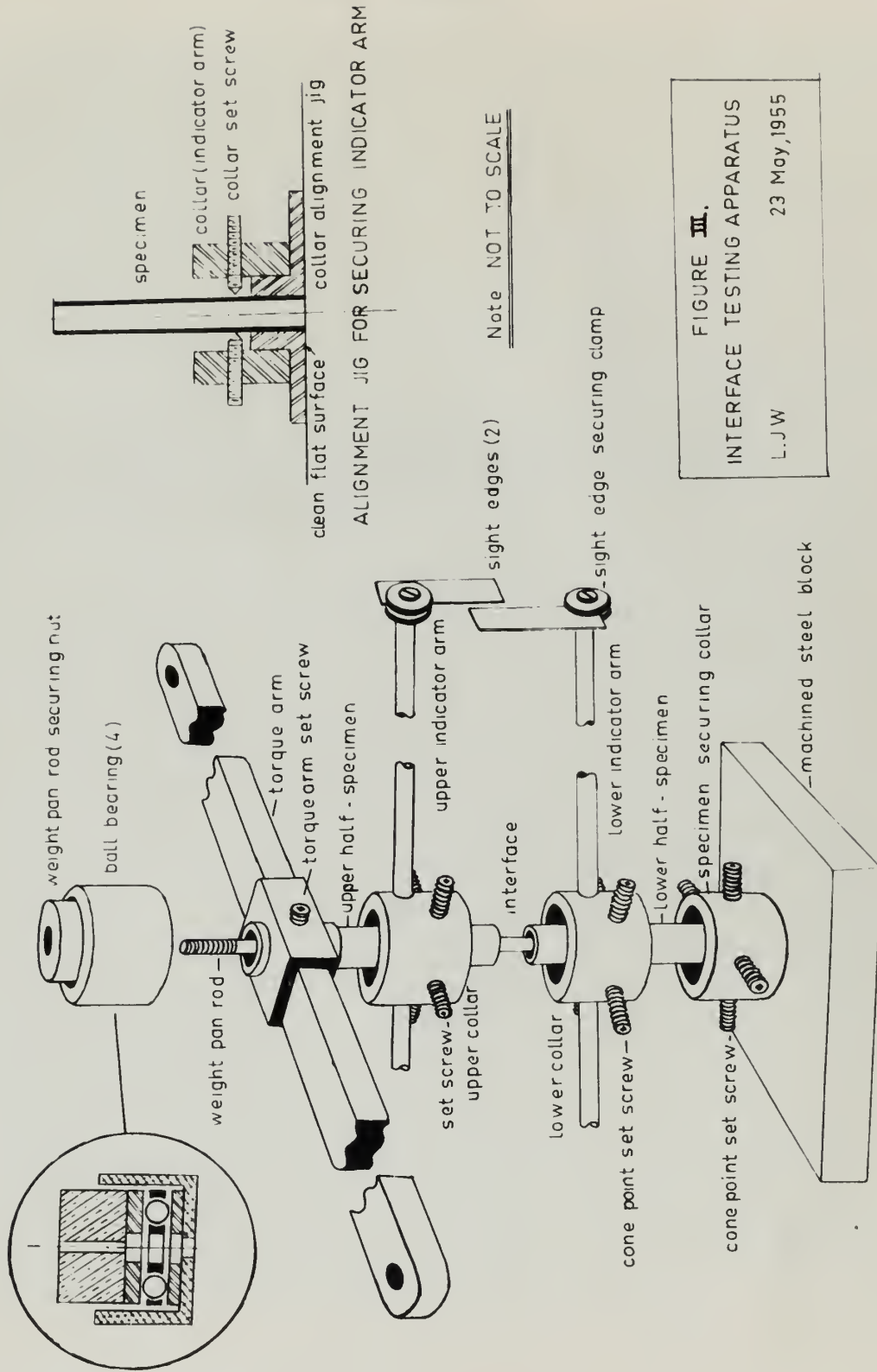


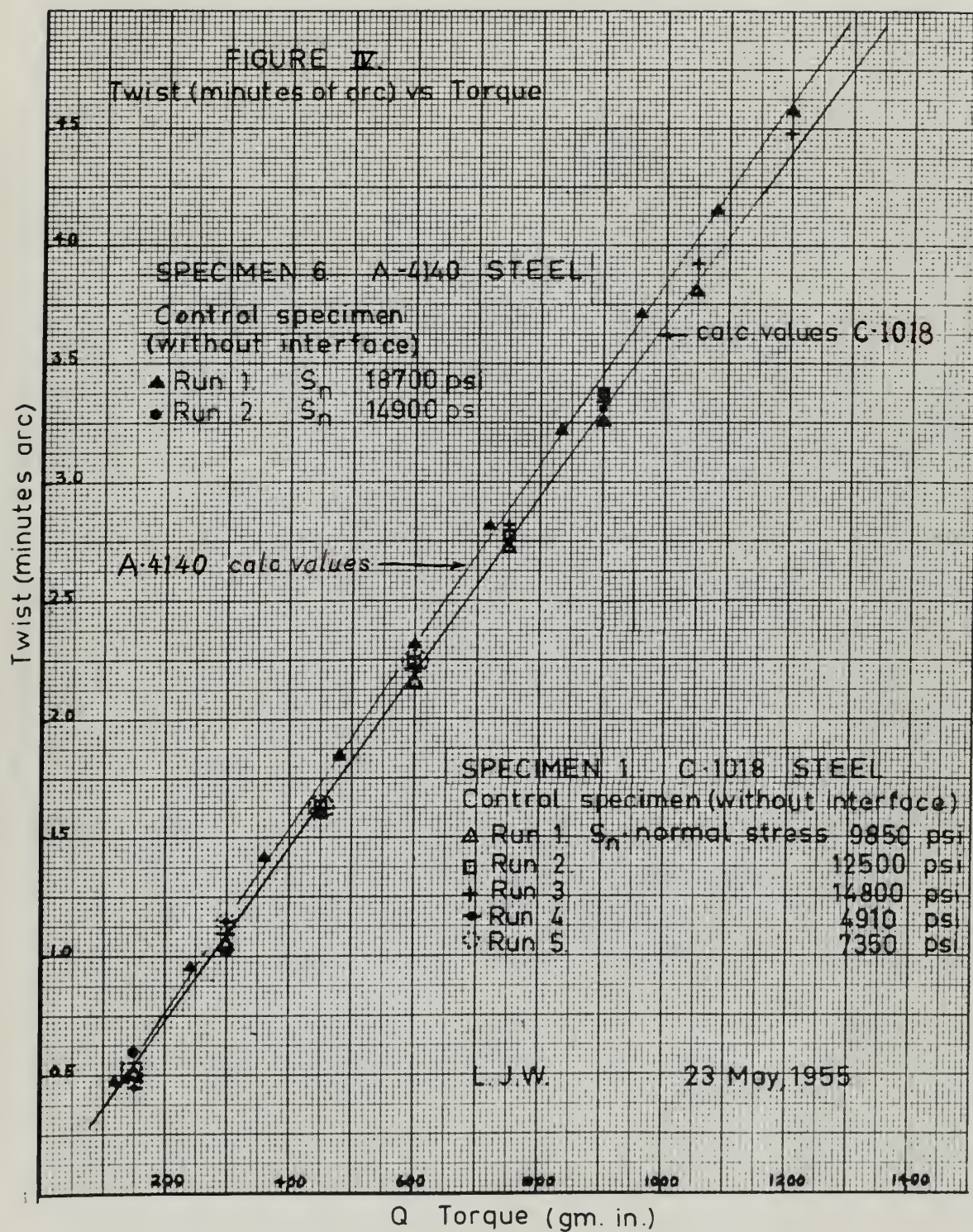
FIGURE III.
INTERFACE TESTING APPARATUS

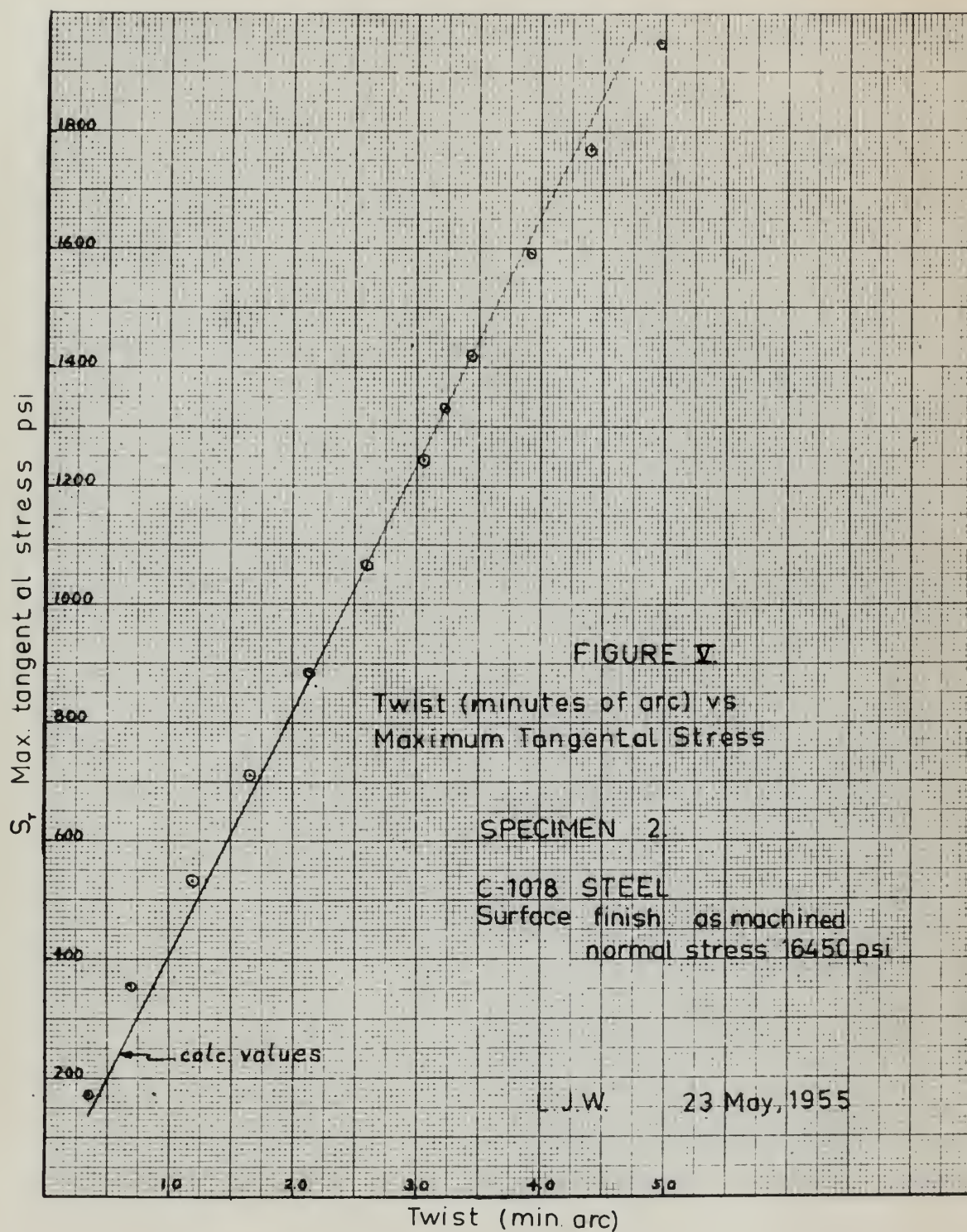
L.J.W

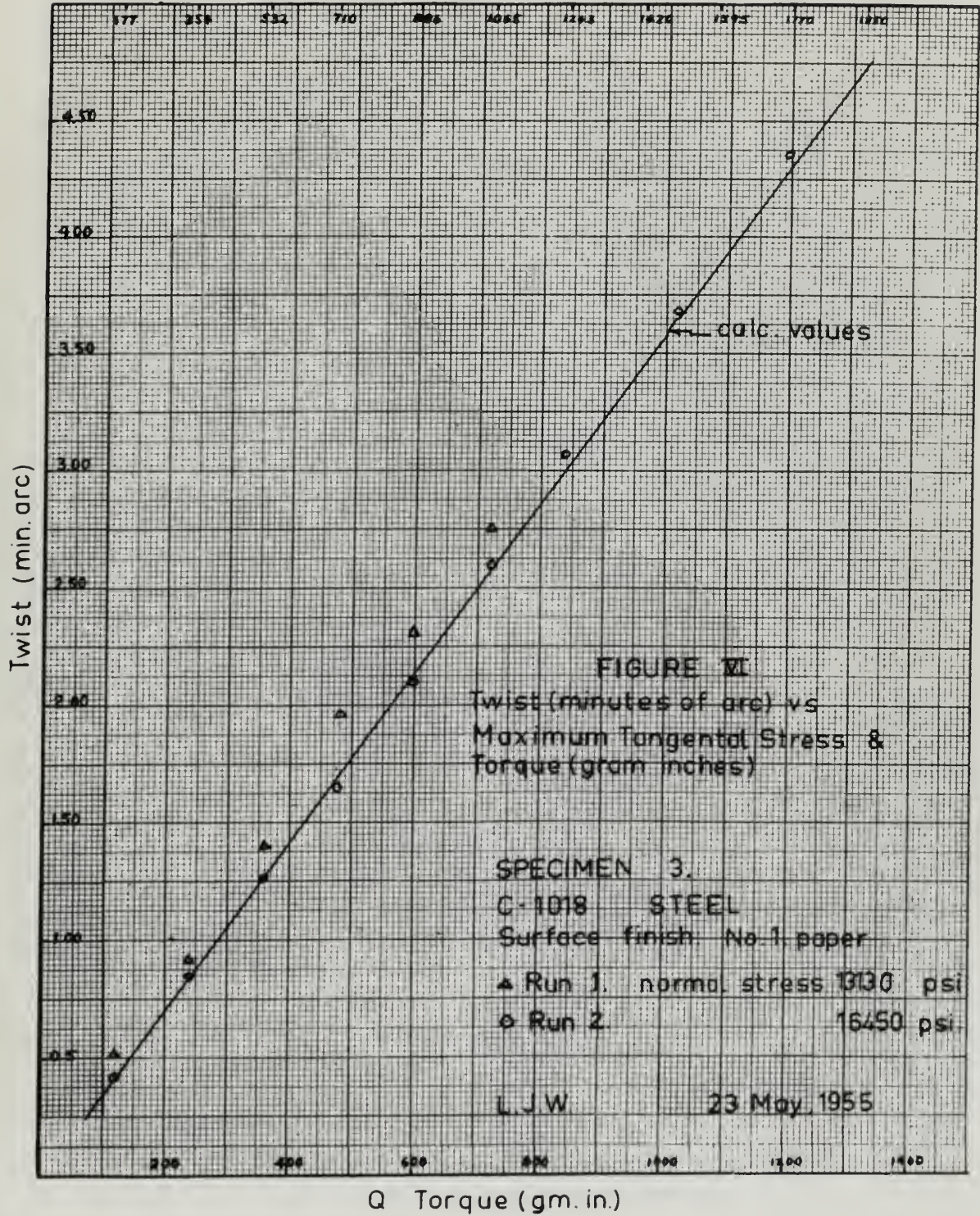
23 May, 1955

STIMULI .III

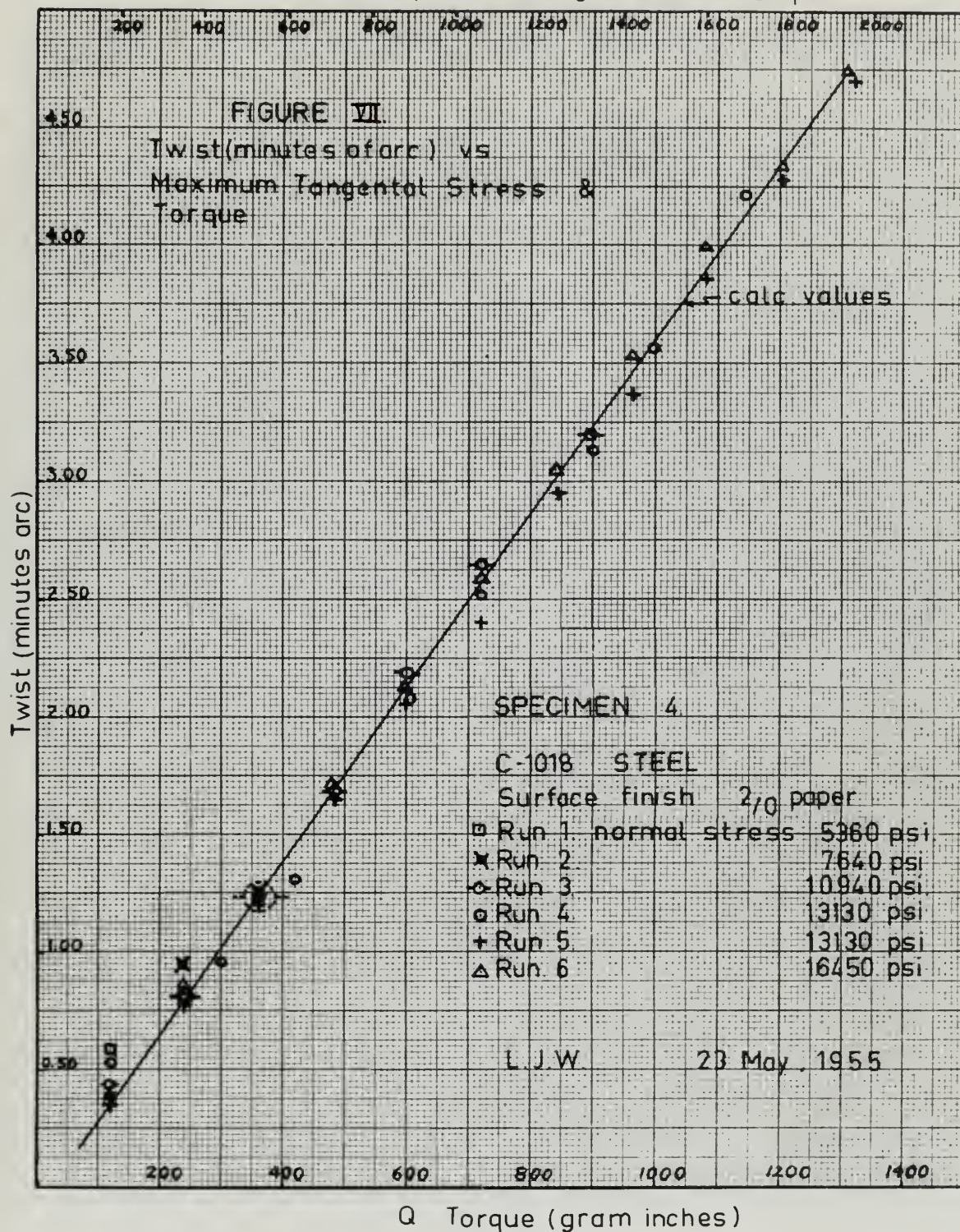
The results of this investigation are shown in
 Figures IV to VII, inclusive.

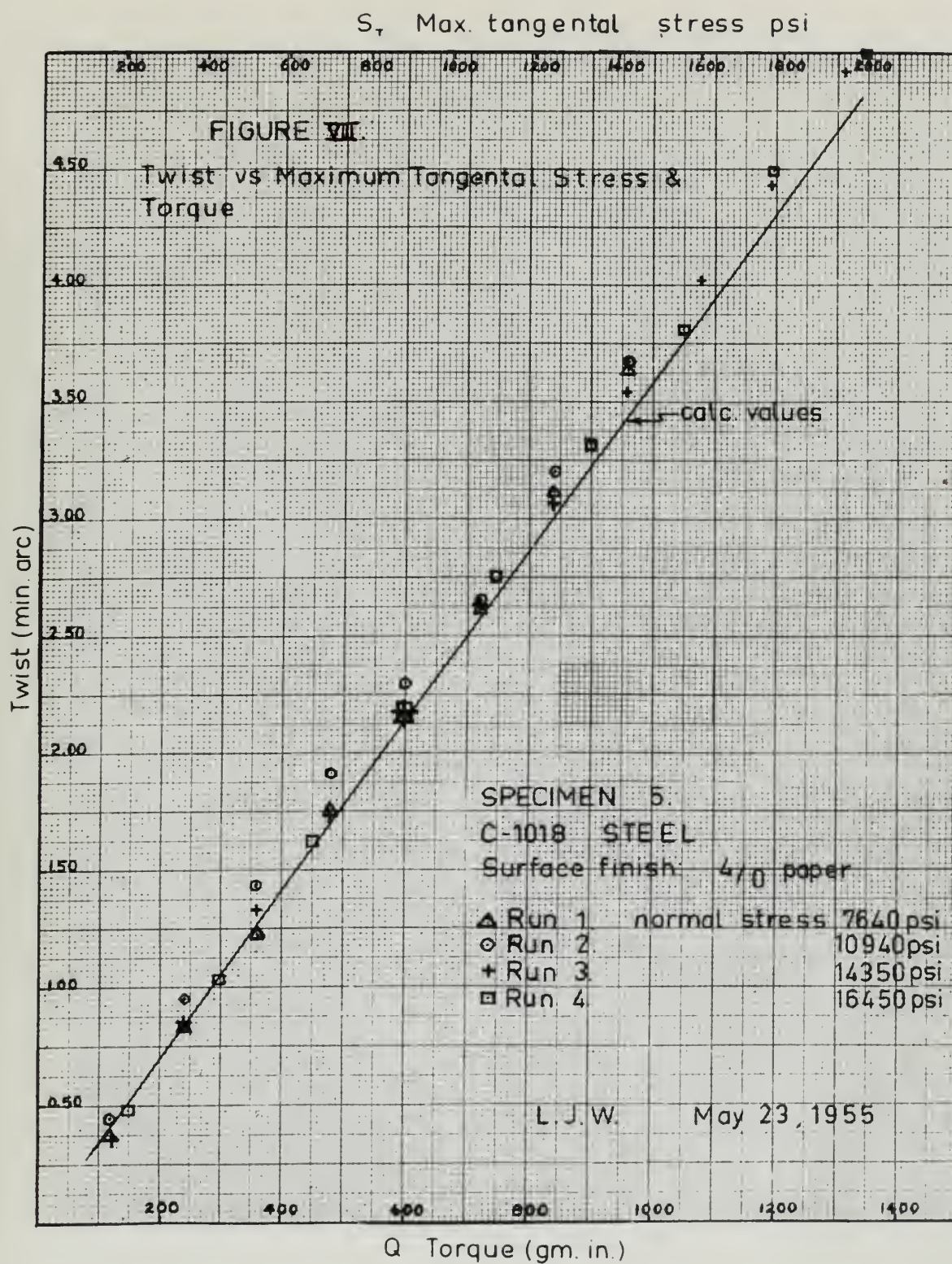




$S_T = \text{Max. tangential stress psi}$


S_r = Max. tangential stress psi





S_r = Max. tangential stress psi

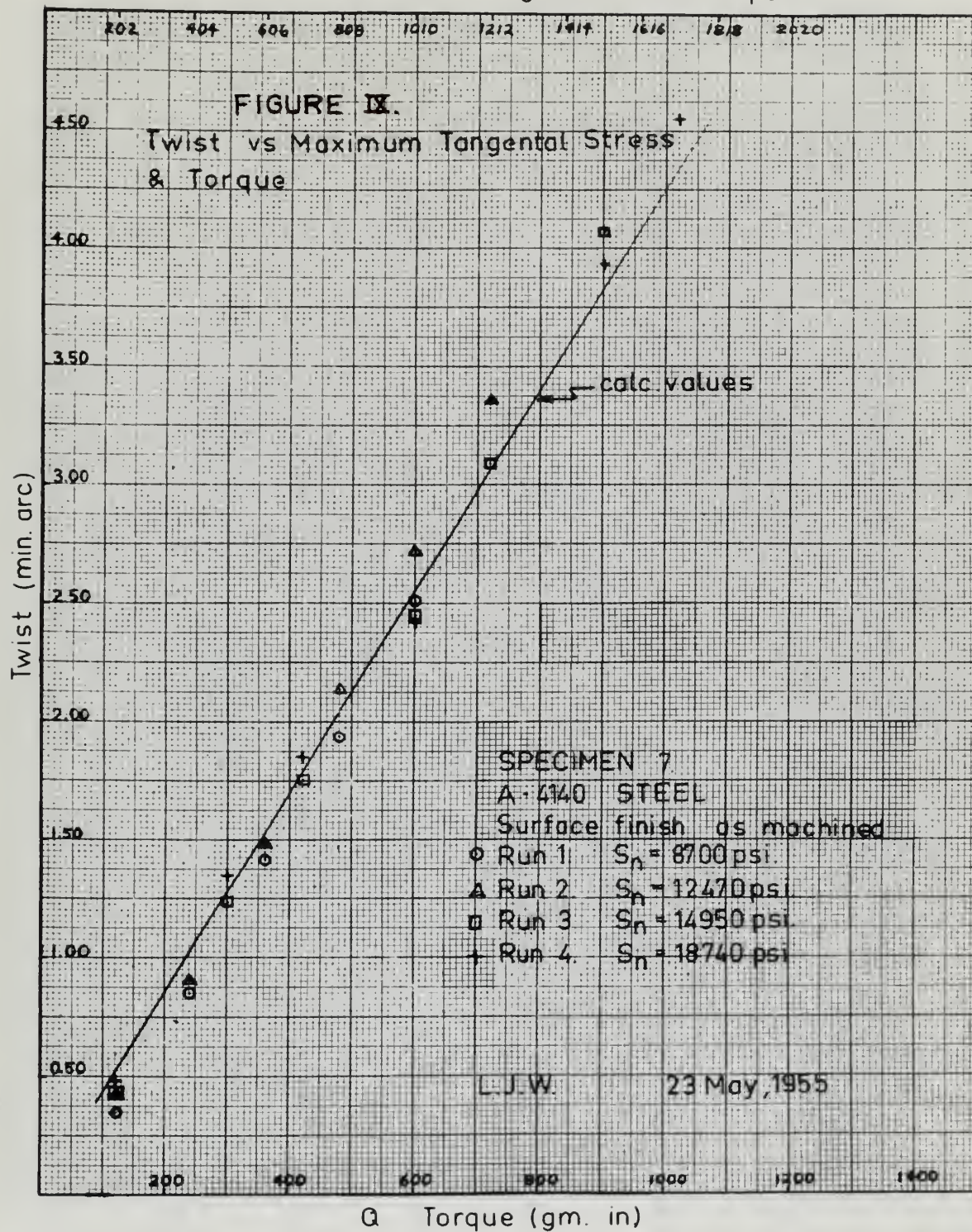


FIGURE X.
TWIST VS MAXIMUM TANGENTIAL STRESS

SPECIMEN 13.

Copper surface finish #1 paper

Run 1 $S_n = 11170$ psi

Run 2. 13360 psi

Run 3. 16700 psi

calc. values Copper

calc. values A-4140

SPECIMEN 8.

A-4140 steel surface finish #1. paper

Run 1. $S_n = 8700$ psi

Run 2. 12470 psi

Run 3. 14950 psi

Run 4. 18740 psi

L.J.W. May 1955

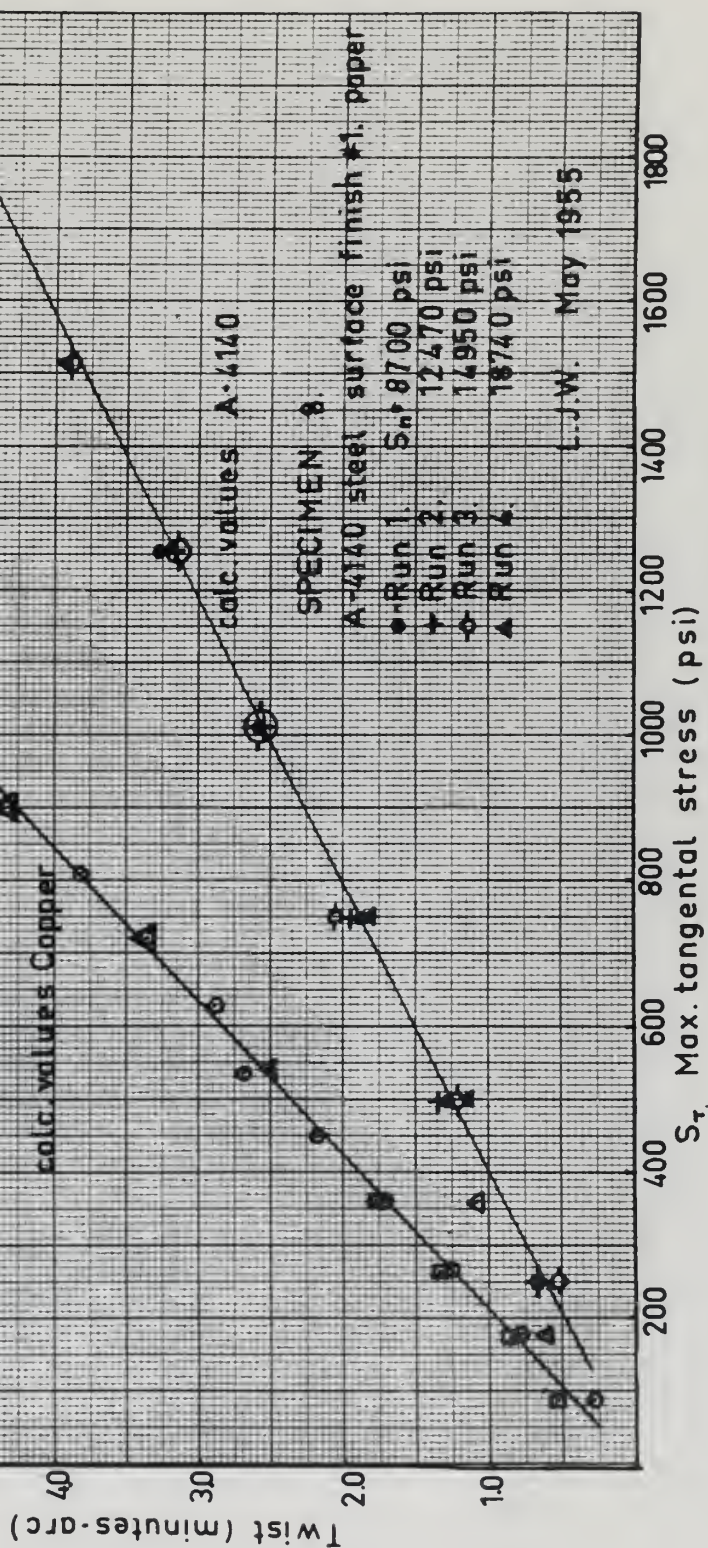


FIGURE XI.

TWIST vs MAXIMUM TANGENTIAL STRESS

SPECIMEN 14.

Copper surface finish 2/0

- ◇ Run 1 $S_n = 4300$ psi
- △ Run 2 7800 psi
- + Run 3 11170 psi
- Run 4 13360 psi
- Run 5 15400 psi

calc. values copper

calc. values A-4140

SPECIMEN 9.

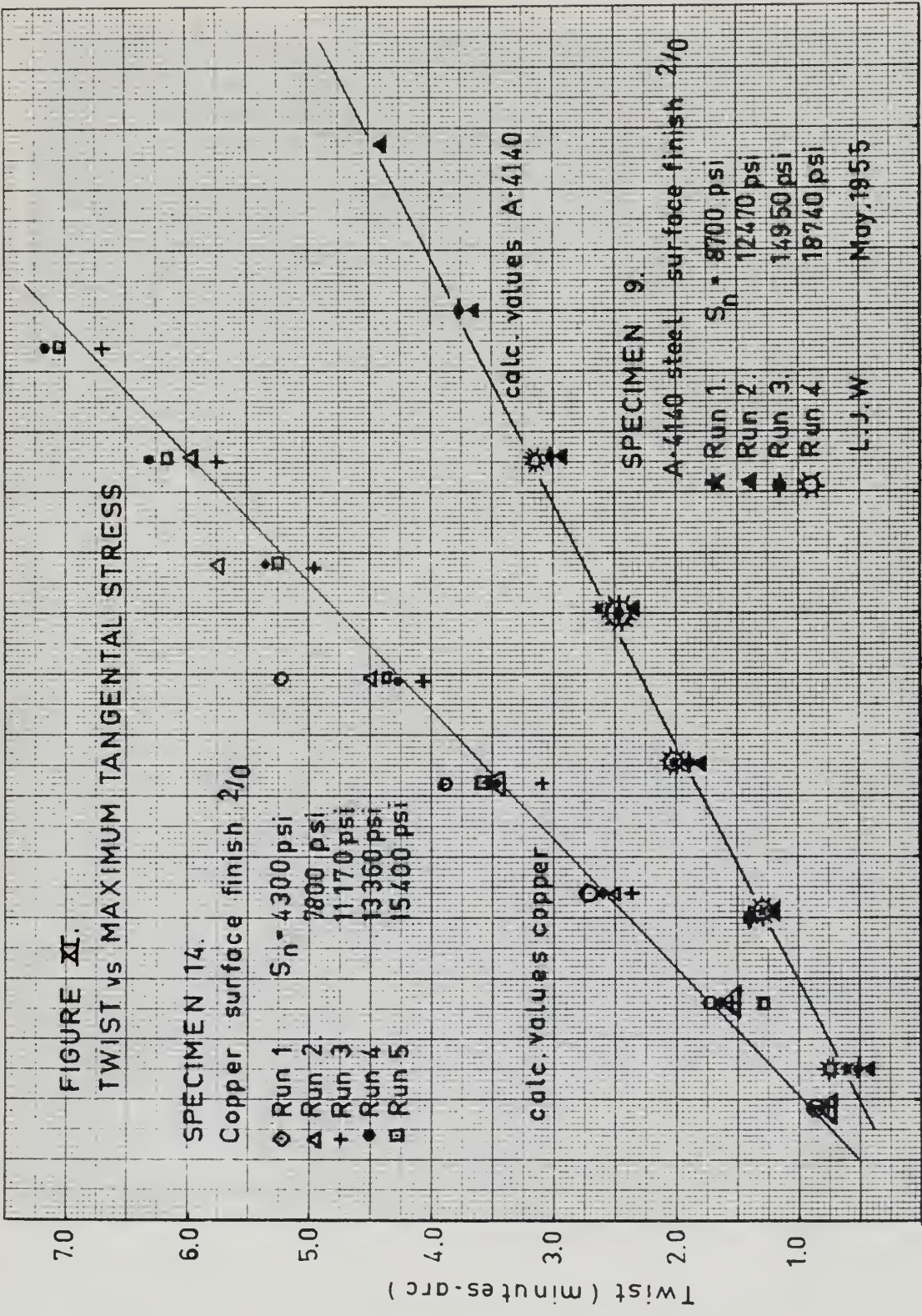
A-4140 steel surface finish 2/0

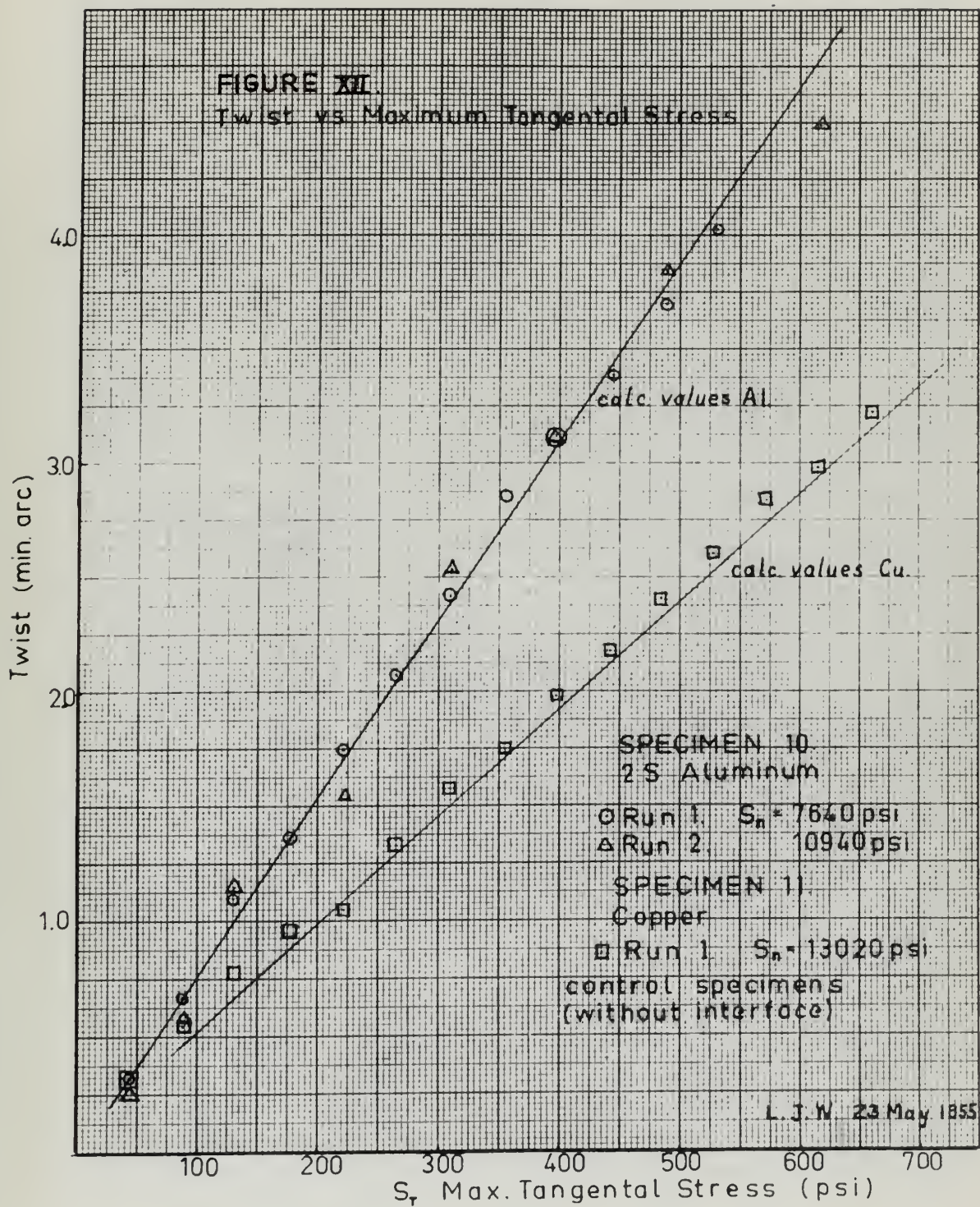
- ★ Run 1 $S_n = 8700$ psi
- △ Run 2 12470 psi
- Run 3 14950 psi
- ⊗ Run 4 18740 psi

L.J.W

May. 1955

S_t Max. Tangential Stress (psi)





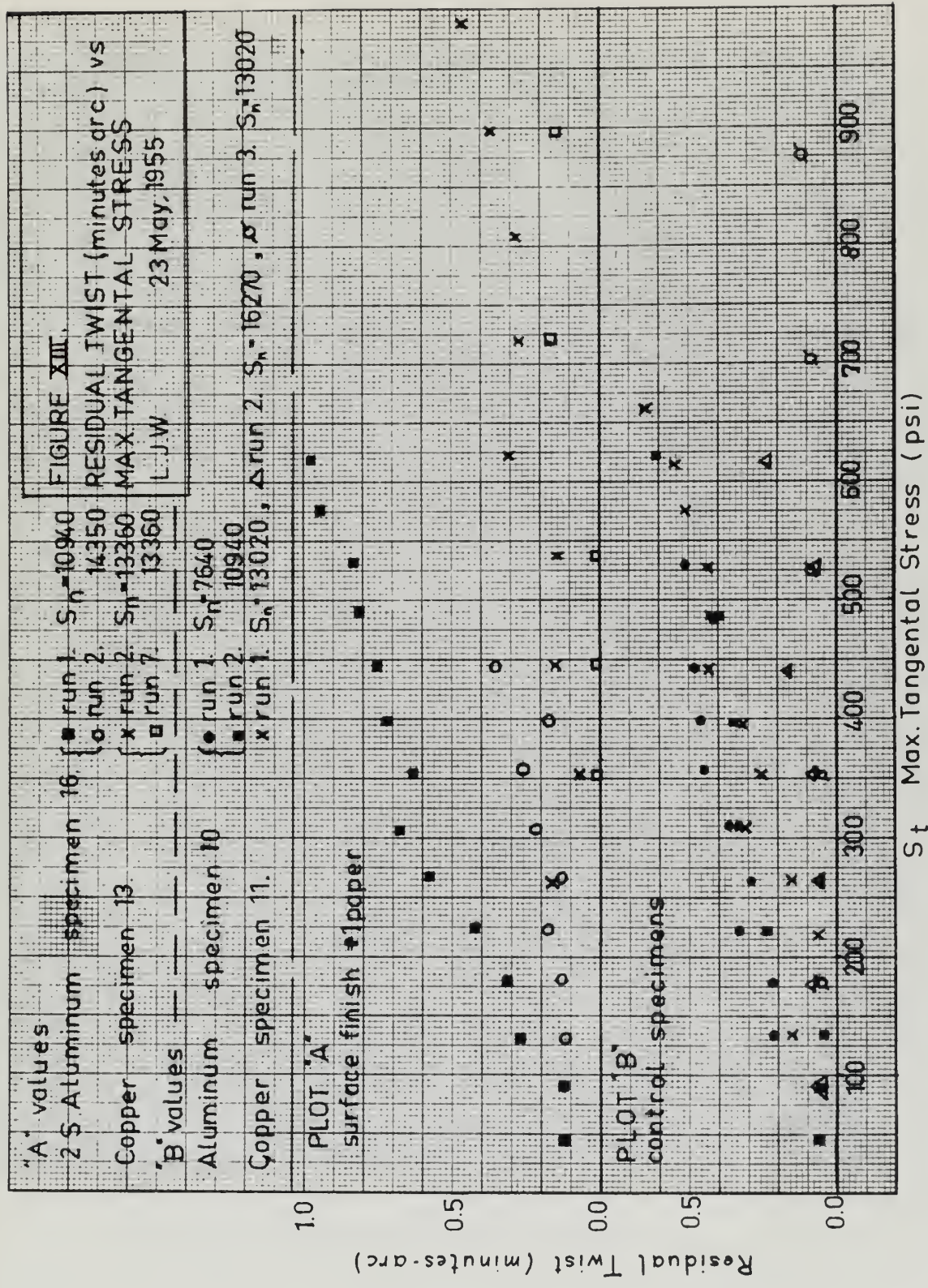


FIGURE XIV

Maximum Tangential Stress vs
Apparent Slip at Interface

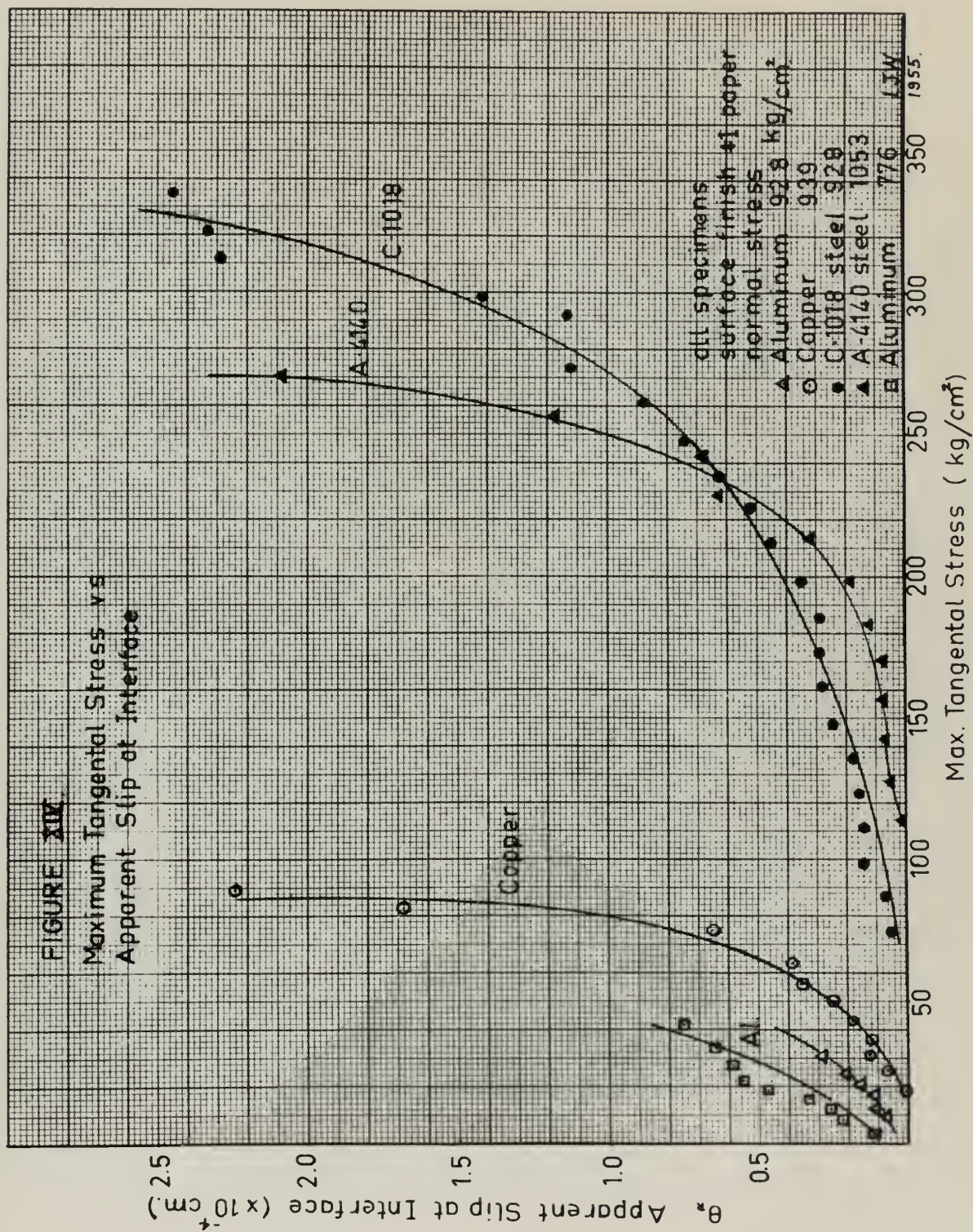
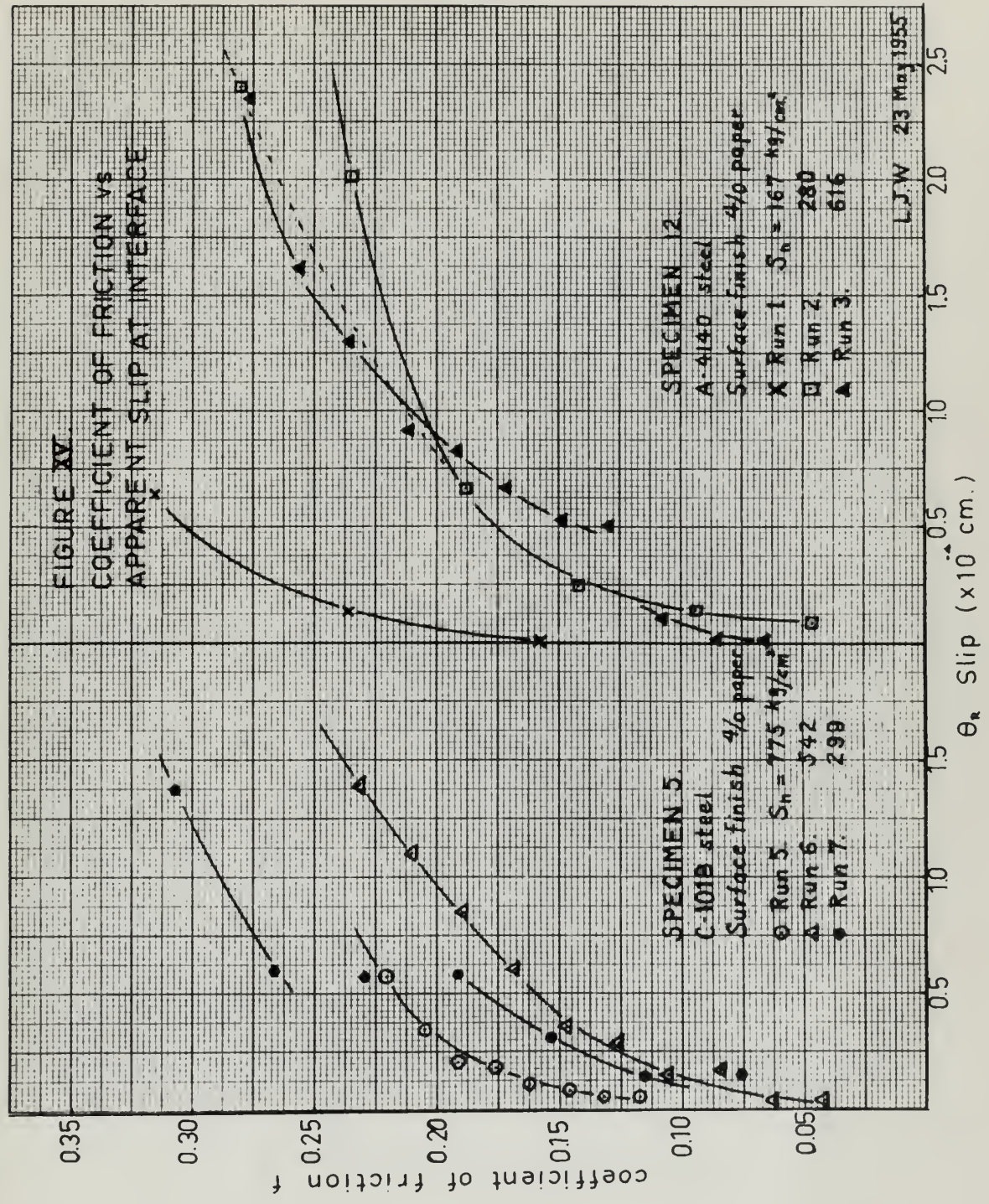


FIGURE XV.

COEFFICIENT OF FRICTION VS
APPARENT SLIP AT INTERFACE



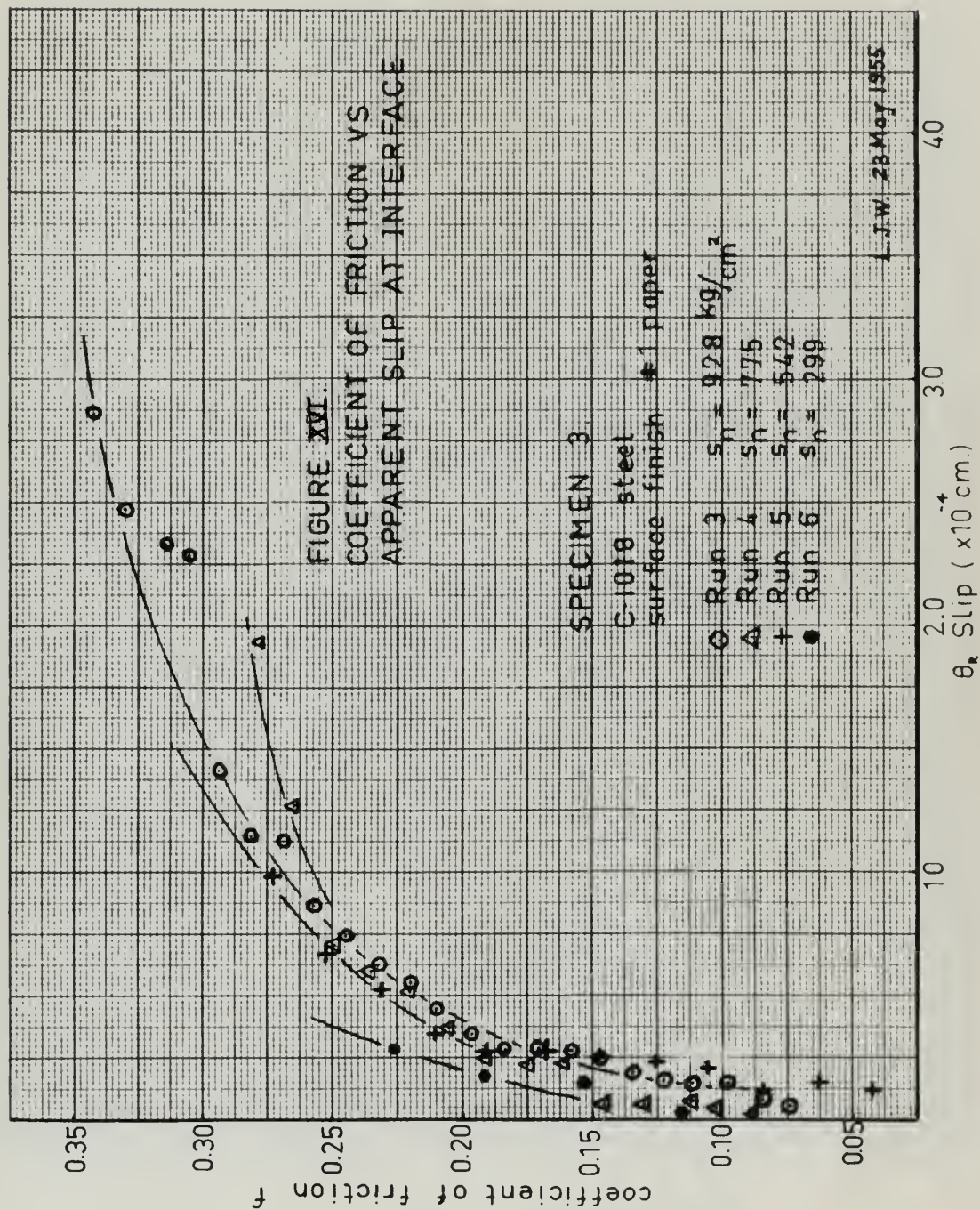


FIGURE XVII.

Coefficient of Friction vs.
Apparent Slip at Interface

0.3

coefficient of friction f

0.2

0.1

1.0

2.0

3.0

4.0

 θ_R Slip ($\times 10^4$ cm.)

SPECIMEN 8

A 4140 surface finish #1 paper

• Run 7 $S_n = 1053$ $\mu g/cm^2$ ▲ Run 8 $S_n = 883$ ○ Run 9 $S_n = 616$ + Run 10 $S_n = 340$

L. J. W. 23 May 1955

 $f = 0.155$ at 0.30×10^4 cm.

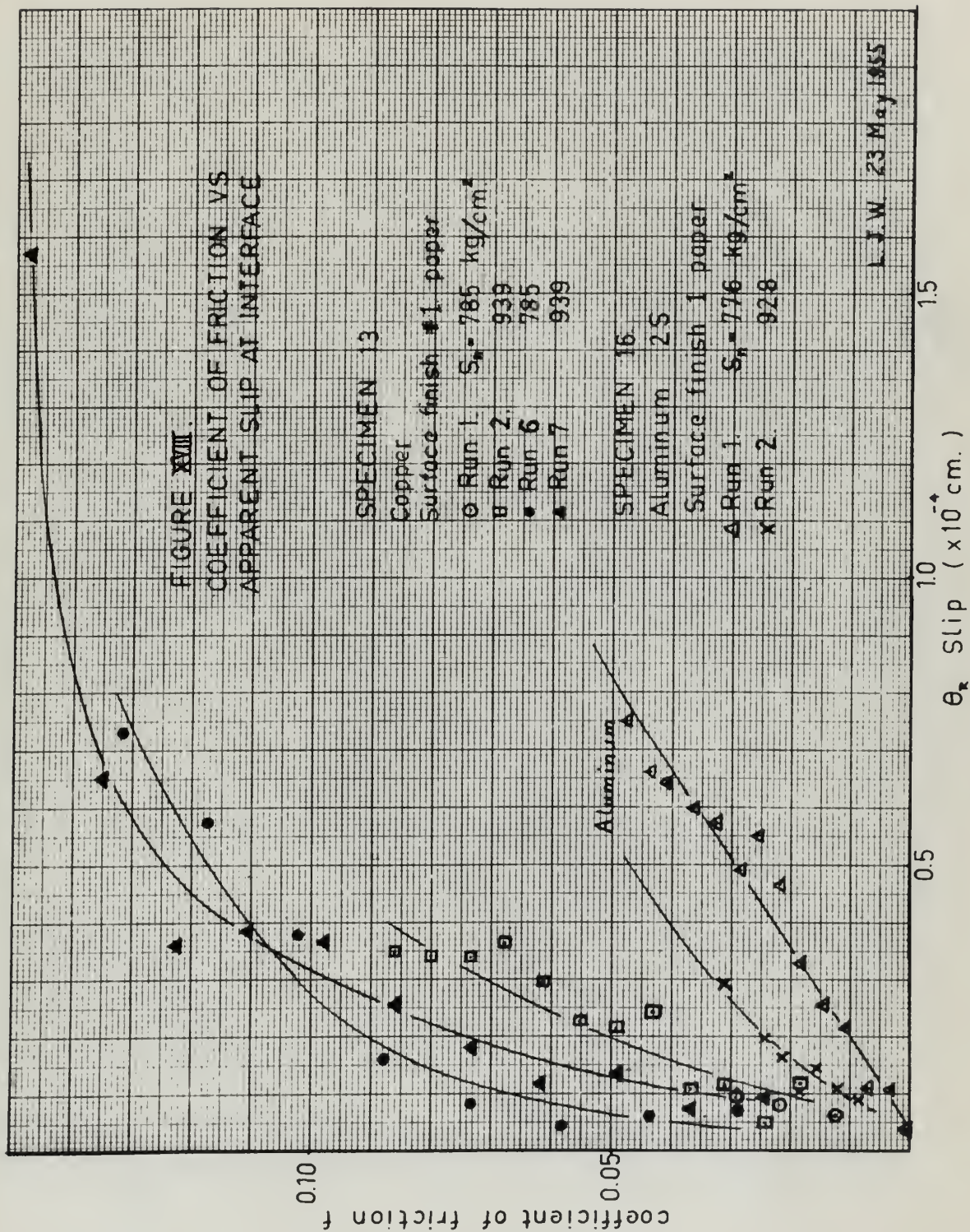
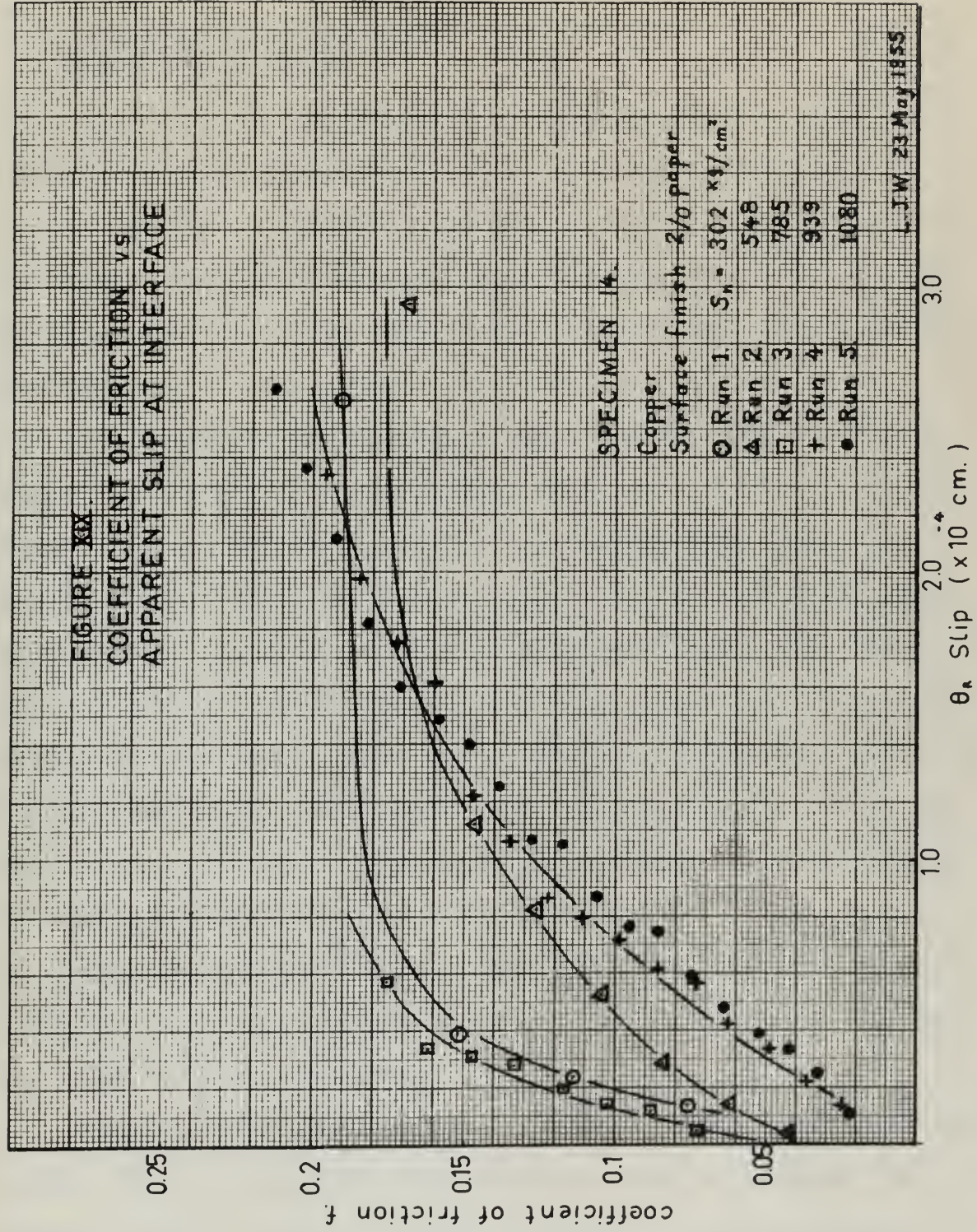


FIGURE XXX.
COEFFICIENT OF FRICTION vs
APPARENT SLIP AT INTERFACE



IV. DISCUSSION OF RESULTS

A. Initial Elastic Behavior of Metal Interfaces

Figures IV and XII compare observed deflections of the control specimens with computed deflections as predicted by elastic theory. All points plotted for the two steel control specimens are within the elastic range, as the test runs were terminated at the first indication of possible permanent deformation.

The values of shear modulus selected for the C-1018 and A-4140 steels were, respectively, 12×10^6 and 11.9×10^6 psi. Marks⁽⁶⁾ gives the range of shear modulus values for all steels, excepting 18-8 stainless, as 11.0 to 11.9×10^6 psi. The computed angle of twist varies inversely with the value of shear modulus. Therefore it can be seen that, with the values of shear modulus selected, the computed deflections will be the minimum expected. As the observed values of twist agree with the minimum computed values, the possibility of excessive elastic twist in the control specimen is eliminated.

The shear modulus values for copper (hard-drawn tough pitch) and 28 Aluminum were given in the Handbook as 6.0 and 3.7×10^6 psi, respectively.

Figures V to VIII show the results of tests conducted with C-1018 steel specimens having various surface finishes and normal loads. Due to the close agreement between observed and

1. Initial Elastic Properties
of Steel Specimens

Figure 1 shows the typical behavior of the control specimens with respect to the initial elastic properties. All points plotted for the two steel specimens are within the limits of the elastic range, as the test was terminated at the first indication of possible permanent deformation.

The values of initial modulus obtained for the 2024 and 7075 alloys were, respectively, 1.5×10^6 and 1.1×10^6 psi. (b) gives the range of initial modulus values for all steels, approximately 1.5×10^6 to 1.1×10^6 psi. The computed slope of initial curves for the value of initial modulus. Therefore it can be seen that, with the values of initial modulus obtained, the computed deformation will be the minimum expected. As the observed values of initial modulus are within the expected values, the possibility of permanent deformation in the control specimen is eliminated.

The initial modulus values for copper (hard-tempered) and 2024 alloy were given in the Appendix as 1.1×10^6 and 1.5×10^6 psi, respectively.

Figure 2 shows the results of tests conducted with 2024 alloy specimens having various degrees of temper. The values of initial modulus are given in the Appendix. The values of initial modulus are given in the Appendix. The values of initial modulus are given in the Appendix.

computed values of deflection for the control specimens, the observed angles of twist are compared with their corresponding theoretical value in this work.

The consistent agreement between test results for specimens with and without interfaces indicates that the interface has very little, if any, effect on the elastic twist.

All test runs with non-ferrous specimens were performed with the lower end of the specimen locked against movement. These test runs extended past the point at which the indicator failed to return to the initial position. The "B" plot of Figure XIII gives the observed values of residual twist recorded for the non-ferrous control specimen runs shown on Figure XII. Hard-drawn electrolytic tough pitch copper has a yield strength of 40,000 psi with 0.5% extension under load. Three successive runs on the copper control specimen show this effect clearly. The recorded values of deformation decreased with each run. Plot "A" of this figure shows the residual twist recorded for similar runs conducted on specimens with a No.1 surface finish. The effects contributed by the metal interface can easily be obtained by subtraction of the plotted values for any two corresponding tests. The point at which slip occurs on the copper specimen is easily noted, as the residual twist value increased sharply at that point.

Figures X and XI compare observed and calculated values of deflection for various test runs on copper and A-4140 steel specimens. These tests further substantiate the results recorded previously for C-1018 steel. Test runs using copper,

[illegible]

C-1018 steel, or A-4140 steel under various conditions of normal loading and with different degrees of surface finish failed to indicate any material contribution by the interface to elastic twist.

B. Initial Frictional Behavior of Metal Interfaces

Figure XIV compares the results of a similar test run conducted on four different metals. Comparing the results of the two steel specimens, it is seen that deformation occurred first in the C-1018 steel. This is attributed to yield in the asperities in the metal interface. C-1018 steel, with a yield strength of 48,000 psi as compared with 131,000 psi for the A-4140, would be expected to yield first. It should be noted that the deformation observed here is of the order of 0.000005 cm. The C-1018 curve crosses the A-4140 line at an apparent slip value of 0.00006 cm. This shows that sliding effects are now predominant, as the A-4140 steel with its smaller coefficient of friction slides more easily than the C-1018 steel.

Deformation in the two non-ferrous specimens commenced at fairly low values of tangential stress. It is interesting to note that the aluminum slid freely, and the copper curve rose sharply, at the same value of θ_R at which the two steel curves crossed. Again it appears that, up to this point, deformation was primarily due to yield in the material, while subsequent failure of the interfacial bonds permitted friction effects to predominate.

Figures IV to XIX indicate that the value of the friction coefficient increases with small increments of slip until the normally expected value is attained, at which point the curve flattens out and free sliding results.

The curves plotted in Figures XVI, XVII, and XIX are all fairly smooth, giving no indication of a transition from interfacial deformation to true slip. The plots on Figures XV and XVIII, in contrast, show prominent breaks and discontinuities in the region below 0.00005 cm of apparent slip. The apparent slip in these cases may be due to slip, deformation of the metal, or combinations of both effects. An accurate evaluation of slip with this apparatus is therefore impossible due to the problem of separating the true slip from the deformations produced by yield effects in the asperities in the metal interfaces.

In evaluating these results, some information on the accuracy of the readings is in order. A discussion of the accuracy of the apparatus follows in Appendix A, Details of Procedure.

$$\theta_R = \pm 1.80 \times 10^{-7} \text{ centimeters}$$

$$\psi_0 = \pm 0.00229 \text{ minutes of arc}$$

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions - Elastic Behavior

1. The metal interface does not contribute materially to elastic twist.
2. Elastic deflections of a metal specimen with an interface agree with values computed by elastic theory for a continuous specimen.
3. The deflections predicted by elastic theory are obtained regardless of metal, surface finish, or normal stress selected. (Normal loads applied were selected so that resulting normal stresses were safely below critical range which would cause buckling or compressive failure of the column.)
4. The predicted elastic deflections are obtained in non-ferrous metals even though extension of the metal under load resulted in small concurrent permanent deformations.

B. Conclusions - Frictional Behavior

1. The value of the coefficient of friction was initially low for extremely small values of slip at the interface.
2. The value of the coefficient increased with small increments of slip up to the normally expected value at which point free sliding resulted.

THEORY OF THE DELTA FUNCTION

1. DEFINITION OF THE DELTA FUNCTION

The delta function $\delta(x)$ is defined as a function which is zero everywhere except at $x=0$, where it is infinite, and whose integral over the whole real line is unity.

It is often written

$\delta(x) = \lim_{\epsilon \rightarrow 0} \frac{1}{\epsilon} \delta_{\epsilon}(x)$ where $\delta_{\epsilon}(x)$ is a function which is zero everywhere except in the interval $[-\epsilon, \epsilon]$, where it is constant and equal to $1/\epsilon$.

The delta function is a special case of the more general function

$\delta(x-a)$ which is zero everywhere except at $x=a$, where it is infinite, and whose integral over the whole real line is unity.

The delta function is a function of the first kind, and is not a function of the second kind.

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(continued)

2. THE DELTA FUNCTION AS A LIMIT OF A FUNCTION

The delta function can be regarded as the limit of a function which is zero everywhere except in the interval $[-\epsilon, \epsilon]$, where it is constant and equal to $1/\epsilon$.

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3. An exact assessment of the increments of slip at the interface was impossible with this experimental technique, due to small amounts of deformation contributed by yield in the asperities in the metal interface. Notwithstanding this factor, the trend indicated that the coefficient of friction starts from zero for zero values of slip and applied stress, and increases with small increments of slip until the normal value is reached.

C. Recommendations

Due to the consistency of the results, both quantitatively and qualitatively, further investigation of metal interfaces for abnormal elastic twist is not recommended.

This apparatus was not designed for investigation of frictional behavior in the slow speed range; therefore modifications of the equipment are deemed necessary prior to any further investigations of the stick slip phenomena with this basic experimental arrangement.

3. In most instances of the treatment of this
 of the infection and laboratory with this experi-
 mental technique, one or more animals of def-
 inite age and sex are used in the experiment
 in the same manner. Notwithstanding this
 factor, the above indicated that the results of
 of infection differ from case to case unless of
 age and applied stress, and infection with well
 treatment of all until the normal value is
 reached.

C. Experimental

One of the objectives of the study, both qualitative
 and quantitative, further investigation of metal
 infection for removal elastic trial is not recommended.
 This objective was not designed for installation of
 technical details in the also used range laboratory equip-
 ment of the equipment are found necessary only in the
 further investigation of the trial with specimens with this
 basic experimental arrangement.

APPENDIX A
DETAILS OF PROCEDURE

DETAILS OF PROCEDURE

In the redesign of the test apparatus, various schemes for measuring angular twist of the specimen were considered. Selection of an optical lever in lieu of the metal indicator arms of the original apparatus was rejected due to the length of light beam required. This would require excessive floor space for the apparatus or would involve the use of a complex prism system. Distribution of the equipment over a large floor space would present a problem in isolating the apparatus from vibrations imparted by the building structure. Another source of error would be encountered in the resolution of the light image on the measuring scale.

The possibility of utilizing interferometry was investigated. Measurement of exceedingly small angles of twist could be obtained by this means, but the cost and complexity of the apparatus required for this work were greater than warranted.

It was decided that a sufficient increase in the sensitivity of the system could be obtained by use of better materials, measuring equipment, and refinements in the experimental method.

The original apparatus utilized an apparatus having an indicator arm length of 7.5" and an optical vernier in which one scale unit represented 0.001 inch of indicator movement.

Estimating the movement of one indicator arm to ± 0.1 scale unit, the resulting accuracy with two arms would be ± 0.2 scale unit.

Results of Experiments

In the redesign of the test apparatus, various changes
 The necessary repairs listed at the beginning were completed.
 Selection of an optical filter in line with the initial indication
 some of the original apparatus was rejected due to the length
 of light beam required. This would require extensive work
 upon the apparatus as would involve the use of a complex
 prism system. Distortion of the equipment over a large field
 of view would present a problem in isolating the apparatus from
 vibrations caused by the building structure. Another source
 of error would be introduced in the resolution of the light
 image on the viewing screen.

The necessity of utilizing interference was investigated.
 Measurement of wavelength could easily be made by the
 method of this experiment, but the need for accuracy of the ap-
 paratus required for this work was greater than anticipated.
 It was decided that a different approach in the design
 of the system would be required by use of better mate-
 rials, measuring equipment, and refinements in the experimental
 method.

The original apparatus utilized an emission filter as
 radiator and length of 7.5" and an optical filter in which
 one side was represented by a 1000 lines of resolution grating.
 Evaluation the movement of the indicator was to 10.1
 scale units, the resulting accuracy was two units in
 10.1 scale units.

$$\psi_o = \frac{\psi_s}{R} \times \frac{180}{\pi} \times 60 = \text{observed twist in minutes of arc.}$$

Therefore accuracy of the original apparatus was

$$\psi_o = \pm \frac{0.0002}{7.5} \times 3440 = \pm 0.092 \text{ minutes of arc.}$$

By the use of a microscope equipped with a 10 x objective and an optical micrometer, the accuracy was increased considerably. The use of the light-weight but rigid tubular indicator arms permitted increasing the value of R to 12.328".

Calibration of the optical micrometer against a micrometer stage showed that one micrometer drum unit represented 0.00004101 inch of indicator movement. Estimating the micrometer readings to ± 0.1 drum unit would result in an accuracy in observed deflections of ± 0.2 drum units. Therefore, accuracy of the present apparatus is

$$\psi_o = \pm \frac{0.000008202}{12.33} \times 3440 = \pm 0.002290 \text{ minutes of arc}$$

The value of apparent slip (θ_R) measured with this apparatus is computed as follows: For the C-1018 steel specimen with the outside diameter of 0.2365" and inside diameter of 0.191", the mean radius (r_m) of the specimen is 0.1069".

Therefore

$$\frac{\theta_R}{r_m} = \pm \frac{0.000008202}{12.33}$$

$$\theta_R = \pm 7.10 \times 10^{-8} \text{ inches}$$

$$\theta_R = \pm 1.80 \times 10^{-7} \text{ centimeters}$$

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

The above property of the initial spectrum was

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

By the use of a spectrograph equipped with a 10 ft objective and an elliptical mirror, the spectrum was measured photographically. The use of the light-weight but still rather heavy camera provided fastness of the order of 1/1000 sec.

Utilization of the optical system showed a sharp edge effect which was not observed from other exposures. The observed band of emission between 4.7 and 4.8 microns was centered at 4.75 microns with width of 0.1 microns. The observed band of emission between 4.7 and 4.8 microns was centered at 4.75 microns with width of 0.1 microns. The observed band of emission between 4.7 and 4.8 microns was centered at 4.75 microns with width of 0.1 microns.

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

The value of k is approximately 1.5, measured with this system. It is compared to values for the 4.7 and 4.8 microns with the values of 1.5 and 1.5. The value of k is approximately 1.5, measured with this system. It is compared to values for the 4.7 and 4.8 microns with the values of 1.5 and 1.5.

Therefore

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

By the use of a spectrograph equipped with a 10 ft objective and an elliptical mirror, the spectrum was measured photographically.

The use of the light-weight but still rather heavy camera provided fastness of the order of 1/1000 sec.

Utilization of the optical system showed a sharp edge effect which was not observed from other exposures.

The observed band of emission between 4.7 and 4.8 microns was centered at 4.75 microns with width of 0.1 microns.

APPENDIX B

SUMMARY OF DATA AND CALCULATIONS

1944

RECEIVED BY THE BUREAU OF THE ARMY

1944

Material: C-1018 Steel

Control Specimen:
(without interface)

$D_o = 0.2365"$

$D_i = 0.191"$

$L = 1.0156"$

$D_o^2 - D_i^2 = 0.01945$

$D_o^4 - D_i^4 = 0.001798$

$A = \frac{\pi}{4}(D_o^2 - D_i^2) = 0.01526$

$S_N = \frac{F_N}{A} = \frac{F_N}{0.01526} \text{ psi}$

$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$

$S_T = 1.475 \times Q_A \text{ psi}$

$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$

$E_s = 12 \times 10^6 \text{ psi}$

$\psi_c = 0.00364 Q_A \text{ min.arc.}$

$\psi_o = 0.01144 \psi_s \text{ min.arc.}$

Run No.1

$F_N = 150 \text{ lb.}$

$S_N = 9850 \text{ psi}$

Run No.2

$F_N = 190.7 \text{ lb.}$

$S_N = 12500 \text{ psi}$

Q_A	S_T	ψ_c	ψ_o
150	221.5	0.547	0.504
300	443	1.093	1.018
450	665	1.640	1.635
600	886	2.185	2.250
750	1107	2.733	2.776
900	1330	3.280	3.380
1050	1550	3.830	- -
1200	1770	4.370	- -

LEAF 5101.0 : Leafwise

INSTRUMENT Leaf-000
(no General function)

2000.0 = $\frac{1}{2}$
1000.0 = $\frac{1}{2}$
1000.0 = $\frac{1}{2}$

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2000.0 = $\frac{1}{2}$

2000.0 = $\frac{1}{2}$

5.03 WINDINGS

2000.0 = $\frac{1}{2}$

2000.0 = $\frac{1}{2}$

5.03 WINDINGS

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2000.0 = $\frac{1}{2}$

SPECIMEN NO.1 (continued)

		<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>
		$F_N = 225.4 \text{ lb.}$	$F_N = 74.91 \text{ lb.}$	$F_N = 111.9 \text{ lb.}$
		$S_N = 14800 \text{ psi}$	$S_N = 4910 \text{ psi}$	$S_N = 7350 \text{ psi}$
Q_A	S_T	ψ_c	ψ_o	ψ_o
150	221.5	0.547	0.457	0.515
300	443	1.093	1.155	1.109
450	665	1.640	- -	1.647
600	886	2.185	- -	2.240
750	1107	2.733		
900	1330	3.280		
1050	1550	3.830		
1200	1770	4.370		

И. В. КУЗНЕЦОВ

[illegible]

Specimen No.2

Material: C-1018 Steel

Surface Finish:
As Machined (Lathe)Specimen No.3

Material: C-1018 Steel

Surface Finish:
No.1 Emery Paper

$$D_o = 0.2365"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00362 Q_A \text{ min.arc.}$$

$$\psi_o = 0.01144 \psi_s \text{ min.arc.}$$

SPECIMEN NO.2SPECIMEN NO.3Run No.1

$$F_N = 251.2 \text{ lb.}$$

$$S_N = 16450 \text{ psi}$$

$$\psi_c$$

$$S_T$$

$$Q_A$$

$$\psi_o$$

$$\psi_o$$

$$\psi_o$$

$$0.355$$

$$177$$

$$120$$

$$0.435$$

$$0.413$$

$$0.8695$$

$$354$$

$$240$$

$$0.918$$

$$0.849$$

$$1.304$$

$$532$$

$$360$$

$$1.410$$

$$1.260$$

$$1.740$$

$$710$$

$$480$$

$$1.925$$

$$1.650$$

$$2.177$$

$$886$$

$$600$$

$$2.315$$

$$2.100$$

$$2.608$$

$$1065$$

$$720$$

$$2.760$$

$$2.590$$

$$3.043$$

$$1243$$

$$840$$

$$-$$

$$3.074$$

$$3.260$$

$$1330$$

$$900$$

$$-$$

$$-$$

$$3.480$$

$$1420$$

$$960$$

$$-$$

$$-$$

$$3.910$$

$$1595$$

$$1080$$

$$-$$

$$-$$

$$4.350$$

$$1770$$

$$1200$$

$$-$$

$$4.400$$

$$4.780$$

$$1950$$

$$1320$$

$$-$$

$$-$$

Commodities

5.08 1000000

[illegible]

Case Study: Illustration

United States
Library of Congress

[illegible]

SPECIMEN NO. 3

Run No. 3 $F_N = 201.29 \text{ lb.}$ $F_N = 41.3 \text{ kg}$ $S_N = 13200 \text{ psi}$ $S_N = 928 \text{ kg/cm}^2$

Q_A	s_t	ψ_R	θ_R	f	Q_A	s_t	ψ_R	θ_R	f
240	24.9	- - -	- - -	0.0245	1920	199.0	0.459	36.20×10^{-6}	0.1960
360	37.4	- - -	- - -	0.0368	2040	211.5	0.573	"	0.2083
480	49.9	- - -	- - -	0.0490	2160	224.0	0.641	"	0.2206
600	62.3	- - -	- - -	0.0613	2280	236.5	0.802	"	0.2326
720	74.9	0.057	4.50×10^{-6}	0.0736	2400	248.7	0.940	"	0.2450
840	87.5	0.080	6.31	0.0859	2520	261.2	1.110	"	0.2575
960	99.9	0.195	15.38	0.0982	2640	273.5	1.420	"	0.2695
1080	112.0	0.183	14.42	0.1103	2760	293.0	1.432	"	0.2820
1200	124.3	0.206	16.25	0.1225	2880	298.5	1.787	"	0.2940
1320	137.0	0.229	18.06	0.1350	3000	311.0	2.910	"	0.3065
1440	149.4	0.321	25.30	0.1470	3120	323.0	2.945	"	0.3186
1560	161.6	0.344	27.12	0.1593	3240	336.0	3.095	"	0.3310
1680	174.3	0.355	28.00	0.1715	3360	348.5	3.660	"	0.3432
1800	186.6	0.344	27.12	0.1840	3480	361.0	- - -	- - -	0.3560

[illegible]

SPECIMEN NO.3 (continued)

Run No.4

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11020 \text{ psi}$$

$$s_n = 775 \text{ kg/cm}^2$$

ϕ_A	ψ_R	θ_R	f
240	- - -	- - -	0.0293
360	- - -	- - -	0.0440
480	- - -	- - -	0.0587
600	- - -	- - -	0.0734
720	0.023	1.81×10^{-6}	0.0880
840	0.057	4.50 "	0.1026
960	0.092	7.25 "	0.1172
1080	0.080	6.31 "	0.1320
1200	0.080	6.31 "	0.1466
1320	0.344	27.12 "	0.1613
1440	0.344	27.12 "	0.1760
1560	0.321	25.30 "	0.1906
1680	0.470	37.08 "	0.2050
1800	0.665	52.45 "	0.2200
1920	0.768	60.60 "	0.2345
2040	0.894	70.50 "	0.2492
2160	1.625	128.0 "	0.2640
2280	2.450	193.2 "	0.2785
2400	- - -	- - -	0.2935

SPECIMEN NO.3 (continued)

Run No.5 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 7700 \text{ psi}$ $s_n = 542 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
240	0.172	13.56×10^{-6}	0.042
360	0.183	"	0.063
480	0.149	"	0.084
600	0.275	"	0.105
720	0.218	"	0.126
840	0.321	"	0.147
960	0.332	"	0.168
1080	0.332	"	0.189
1200	0.470	"	0.210
1320	0.665	"	0.231
1440	0.860	"	0.252
1560	1.250	"	0.273
1680	- - -	- - -	0.294

Run No.6 $F_N = 64.8 \text{ lb.}$ $F_N = 29.4 \text{ kg}$ $S_N = 4250 \text{ psi}$ $s_n = 299 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
240	- - -	- - -	0.0762
360	0.057	4.50×10^{-6}	0.1144
480	0.183	"	0.1522
600	0.218	"	0.1905
720	3.630	"	0.2280
840	- - -	- - -	0.2660

Electronics Engineering

Electronics

$$V_1 = 100 \times 10^3$$

$$V_2 = 100 \times 10^3$$

$$V_3 = 100 \times 10^3$$

$$V_4 = 100 \times 10^3$$

	V_1	V_2	V_3	V_4
1	100	100	100	100
2	100	100	100	100
3	100	100	100	100
4	100	100	100	100
5	100	100	100	100
6	100	100	100	100
7	100	100	100	100
8	100	100	100	100
9	100	100	100	100
10	100	100	100	100

Electronics

$$V_1 = 100 \times 10^3$$

$$V_2 = 100 \times 10^3$$

$$V_3 = 100 \times 10^3$$

$$V_4 = 100 \times 10^3$$

	V_1	V_2	V_3	V_4
1	100	100	100	100
2	100	100	100	100
3	100	100	100	100
4	100	100	100	100
5	100	100	100	100
6	100	100	100	100
7	100	100	100	100
8	100	100	100	100
9	100	100	100	100
10	100	100	100	100

SPECIMEN NO.4

Material: C-1018 Steel

Surface Finish:
2/0 paper

$$D_o = 0.2365"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00362 Q_A \text{ min. arc.}$$

$$\psi_c = 0.01144 \psi_s \text{ min. arc.}$$

Run No.1

$$F_N = 81.75 \text{ lb. } F_N = 116.3 \text{ lb. } F_N = 167 \text{ lb.}$$

$$S_N = 5360 \text{ psi } S_N = 7640 \text{ psi } S_N = 10940 \text{ psi}$$

Q_A	S_T	ψ_c	ψ_o	ψ_o
120	177	0.4345	0.619	0.447
240	354	0.8695	1.317	0.825
300	443	1.090	- - -	- - -
360	532	1.304	- - -	1.237
420	620	1.520	- - -	- - -
480	710	1.740	- - -	1.674
600	886	2.177	- - -	2.200
720	1065	2.608	- - -	2.650
840	1243	3.040	- - -	3.200
900	1330	3.260	- - -	- - -
960	1420	3.470	- - -	- - -
1020	1505	3.690	- - -	- - -
1080	1595	3.910	- - -	- - -
1140	1680	4.130	- - -	- - -
1200	1770	4.350	- - -	- - -
1320	1950	4.775	- - -	- - -

Run No.2

SPECIMEN NO.4 (continued)

<u>Run No.4</u>			<u>Run No.5</u>			<u>Run No.6</u>		
$F_N = 200.3 \text{ lb.}$			$F_N = 200.3 \text{ lb.}$			$F_N = 251.2 \text{ lb.}$		
$S_N = 13130 \text{ psi}$			$S_N = 13130 \text{ psi}$			$S_N = 16450 \text{ psi}$		
Q_A	S_T	ψ_c	ψ_o	ψ_o	ψ_o			
120	177	0.4345	0.526	0.367	0.378			
240	354	0.8695	0.814	0.780	0.860			
300	443	1.090	0.953	- - -	- - -			
360	532	1.304	- - -	1.204	1.225			
420	620	1.520	1.306	- - -	- - -			
480	710	1.740	- - -	1.660	1.706			
600	886	2.177	2.085	2.061	2.130			
720	1065	2.608	2.520	2.400	2.590			
840	1243	3.040	- - -	2.956	3.050			
900	1330	3.260	3.130	- - -	- - -			
960	1420	3.470	- - -	3.370	3.525			
1020	1505	3.690	3.670	- - -	- - -			
1080	1595	3.910	- - -	3.850	4.000			
1140	1680	4.130	4.260	- - -	- - -			
1200	1770	4.350	- - -	4.275	4.340			
1320	1950	4.775	- - -	- - -	4.765			

SPECIMEN NO.5

Material: C-1018 Steel

Surface Finish:
4/0 paper

$$D_o = 0.2365"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = 0.00362 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 116.3 \text{ lb.}$$

$$S_N = 7640 \text{ psi}$$

Run No.2

$$F_N = 167 \text{ lb.}$$

$$S_N = 10940 \text{ psi}$$

Q_A	S_T	ψ_c	ψ_o	ψ_o
120	177	0.4345	0.378	0.446
150	221	0.543	- - -	- - -
240	354	0.8695	0.836	0.940
300	443	1.090	- - -	- - -
360	532	1.304	1.237	1.443
450	664	1.627	- - -	- - -
480	710	1.740	1.750	1.912
600	886	2.177	2.154	2.300
720	1065	2.608	2.610	2.656
750	1105	2.714	- - -	- - -
840	1243	3.040	3.120	3.208
900	1330	3.260	- - -	- - -
960	1420	3.470	3.640	3.676
1050	1550	3.800	- - -	- - -
1080	1595	3.910	- - -	- - -
1200	1770	4.350	- - -	4.420
1320	1950	4.775	- - -	- - -
1350	1990	4.885	- - -	- - -

Food & Drug Administration

1998

$\theta^0 = \theta^{15792}$

$$m^2 = 0.7074$$
$$T = T_{\text{eff}} + T_{\text{eff}}^2$$
$$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$$
$$m_{\pi^0} = 0.0077 \text{ GeV}$$
 $\sigma = 0.01250 \text{ m}^2$
$$\frac{1}{\lambda} = \frac{1}{\lambda_0} + \frac{1}{\lambda_1}$$
$$\log_{10} \frac{1}{1 - \gamma} = 2.1 \approx \gamma$$
[illegible] $\phi = \text{angle between } \vec{r} \text{ and } \vec{r}_0$

8.52 026 1 100.000

$$A^2 = 370 \times 10^3 \quad A^3 = 10^4 \times 10^3$$
$$- \frac{1}{2} \frac{d^2}{dt^2} \ln \frac{1}{\det \mathcal{G}} = \frac{1}{2} \frac{d^2}{dt^2} \ln \det \mathcal{G}$$

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SPECIMEN NO. 5 (continued)

		<u>Run No. 3</u>		<u>Run No. 4</u>	
		$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
		$S_N = 14350 \text{ psi}$		$S_N = 16450 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o	
120	177	0.4345	0.344	- - -	
150	221	0.543	- - -	0.493	
240	354	0.8695	0.847	- - -	
300	443	1.090	- - -	1.040	
360	532	1.304	1.340	- - -	
450	664	1.627	- - -	1.615	
480	710	1.740	1.730	- - -	
600	886	2.177	2.185	2.185	
720	1065	2.608	2.635	- - -	
750	1105	2.714	- - -	2.760	
840	1243	3.040	3.080	- - -	
900	1330	3.260	- - -	3.332	
960	1420	3.470	3.550	- - -	
1050	1550	3.800	- - -	3.800	
1080	1595	3.910	4.020	- - -	
1200	1770	4.350	4.465	4.500	
1320	1950	4.775	4.930	- - -	
1350	1990	4.885	- - -	5.020	

Left side		Right side	
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
1.000	1.000	1.000	1.000
1.001	1.001	1.001	1.001
1.002	1.002	1.002	1.002
1.003	1.003	1.003	1.003
1.004	1.004	1.004	1.004
1.005	1.005	1.005	1.005
1.006	1.006	1.006	1.006
1.007	1.007	1.007	1.007
1.008	1.008	1.008	1.008
1.009	1.009	1.009	1.009
1.010	1.010	1.010	1.010
1.011	1.011	1.011	1.011
1.012	1.012	1.012	1.012
1.013	1.013	1.013	1.013
1.014	1.014	1.014	1.014
1.015	1.015	1.015	1.015
1.016	1.016	1.016	1.016
1.017	1.017	1.017	1.017
1.018	1.018	1.018	1.018
1.019	1.019	1.019	1.019
1.020	1.020	1.020	1.020
1.021	1.021	1.021	1.021
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1.023	1.023	1.023	1.023
1.024	1.024	1.024	1.024
1.025	1.025	1.025	1.025
1.026	1.026	1.026	1.026
1.027	1.027	1.027	1.027
1.028	1.028	1.028	1.028
1.029	1.029	1.029	1.029
1.030	1.030	1.030	1.030
1.031	1.031	1.031	1.031
1.032	1.032	1.032	1.032
1.033	1.033	1.033	1.033
1.034	1.034	1.034	1.034
1.035	1.035	1.035	1.035
1.036	1.036	1.036	1.036
1.037	1.037	1.037	1.037
1.038	1.038	1.038	1.038
1.039	1.039	1.039	1.039
1.040	1.040	1.040	1.040
1.041	1.041	1.041	1.041
1.042	1.042	1.042	1.042
1.043	1.043	1.043	1.043
1.044	1.044	1.044	1.044
1.045	1.045	1.045	1.045
1.046	1.046	1.046	1.046
1.047	1.047	1.047	1.047
1.048	1.048	1.048	1.048
1.049	1.049	1.049	1.049
1.050	1.050	1.050	1.050
1.051	1.051	1.051	1.051
1.052	1.052	1.052	1.052
1.053	1.053	1.053	1.053
1.054	1.054	1.054	1.054
1.055	1.055	1.055	1.055
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1.058	1.058	1.058	1.058
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1.060	1.060	1.060	1.060
1.061	1.061	1.061	1.061
1.062	1.062	1.062	1.062
1.063	1.063	1.063	1.063
1.064	1.064	1.064	1.064
1.065	1.065	1.065	1.065
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1.067	1.067	1.067	1.067
1.068	1.068	1.068	1.068
1.069	1.069	1.069	1.069
1.070	1.070	1.070	1.070
1.071	1.071	1.071	1.071
1.072	1.072	1.072	1.072
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1.074	1.074	1.074	1.074
1.075	1.075	1.075	1.075
1.076	1.076	1.076	1.076
1.077	1.077	1.077	1.077
1.078	1.078	1.078	1.078
1.079	1.079	1.079	1.079
1.080	1.080	1.080	1.080
1.081	1.081	1.081	1.081
1.082	1.082	1.082	1.082
1.083	1.083	1.083	1.083
1.084	1.084	1.084	1.084
1.085	1.085	1.085	1.085
1.086	1.086	1.086	1.086
1.087	1.087	1.087	1.087
1.088	1.088	1.088	1.088
1.089	1.089	1.089	1.089
1.090	1.090	1.090	1.090
1.091	1.091	1.091	1.091
1.092	1.092	1.092	1.092
1.093	1.093	1.093	1.093
1.094	1.094	1.094	1.094
1.095	1.095	1.095	1.095
1.096	1.096	1.096	1.096
1.097	1.097	1.097	1.097
1.098	1.098	1.098	1.098
1.099	1.099	1.099	1.099
1.100	1.100	1.100	1.100

SPECIMEN NO.5

Run No.5

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_H = 11020 \text{ psi}$$

$$s_n = 775 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
240	24.9	- - -	- - -	0.0293
360	37.4	- - -	- - -	0.0440
480	49.9	- - -	- - -	0.0587
600	62.3	- - -	- - -	0.0734
720	74.9	- - -	- - -	0.0880
840	87.5	- - -	- - -	0.1026
960	99.9	0.069	5.44×10^{-6}	0.1172
1080	112.0	0.069	5.44 "	0.1320
1200	124.3	0.114	8.98 "	0.1466
1320	137.0	0.151	11.90 "	0.1613
1440	149.4	0.218	17.16 "	0.1760
1560	161.6	0.264	20.80 "	0.1906
1680	174.3	0.447	35.25 "	0.2050
1800	186.6	0.734	57.80 "	0.2200

λ	λ^0	λ^1	λ^2	λ^3
1980.0	- - -	- - -	7.54	745
2000.0	- - -	- - -	4.74	230
2050.0	- - -	- - -	0.91	091
2100.0	- - -	- - -	1.95	204
2200.0	- - -	- - -	7.47	737
2250.0	- - -	- - -	1.74	173
2300.0	- - -	- - -	0.77	076
2350.0	- 11.2	980.0	0.11	011
2400.0	+ 11.2	980.0	0.11	011
2450.0	- 07.2	111.0	0.11	011
2500.0	+ 07.11	111.0	0.11	011
2550.0	+ 01.71	111.0	0.11	011
2600.0	+ 00.05	111.0	0.11	011
2650.0	+ 01.01	111.0	0.11	011
2700.0	+ 03.72	111.0	0.11	011

SPECIMEN NO.5 (continued)

Run No.6

$F_N = 117.41 \text{ lb.}$

$F_N = 53.3 \text{ kg}$

$S_N = 770 \text{ psi}$

$s_n = 542 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
240	- - -	- - -	- - -
360	0.034	2.68×10^{-6}	0.042
480	0.046	3.63	0.063
600	0.218	17.20	0.084
720	0.183	14.42	0.105
840	0.367	28.90	0.126
960	0.458	36.10	0.147
1080	0.780	61.50	0.168
1200	1.075	84.70	0.189
1320	1.396	109.80	0.210
1440	1.775	139.80	0.231
1560	- - -	- - -	0.252

Run No.7

$F_N = 64.78 \text{ lb.}$

$F_N = 29.4 \text{ kg}$

$S_N = 4250 \text{ psi}$

$s_n = 299 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
240	0.183	14.42×10^{-6}	0.076
360	0.183	14.42	0.114
480	0.412	32.50	0.152
600	0.734	57.80	0.191
720	0.734	57.80	0.228
840	0.768	60.60	0.266
960	1.752	138.2	0.305

(newifree) 6.08 newifree

Final Data

$$100 \text{ mV} = 10^3$$

$$10 \text{ mV} = 10^2$$

$$100 \text{ mV} = 10^3$$

$$100 \text{ mV} = 10^3$$

10^3	10^2	10^1	10^0
200.0	10.0	10.0	10.0
100.0	10.0	10.0	10.0
50.0	10.0	10.0	10.0
20.0	10.0	10.0	10.0
10.0	10.0	10.0	10.0
5.0	10.0	10.0	10.0
2.0	10.0	10.0	10.0
1.0	10.0	10.0	10.0

Final Data

$$100 \text{ mV} = 10^3$$

$$10 \text{ mV} = 10^2$$

$$100 \text{ mV} = 10^3$$

$$100 \text{ mV} = 10^3$$

10^3	10^2	10^1	10^0
200.0	10.0	10.0	10.0
100.0	10.0	10.0	10.0
50.0	10.0	10.0	10.0
20.0	10.0	10.0	10.0
10.0	10.0	10.0	10.0
5.0	10.0	10.0	10.0
2.0	10.0	10.0	10.0
1.0	10.0	10.0	10.0

SPECIMEN NO.6

Material: A-4140 Steel

Control Specimen
(without interface)

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 0.9063"$$

$$D_o^2 - D_i^2 = 0.01711$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$$

$$S_T = 1.684 Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00382 Q_A$$

$$E_s = 11.9 \times 10^6 \text{ psi}$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 251.2 \text{ lb.}$$

$$S_N = 18700 \text{ psi}$$

Q_A	S_T	ψ_c	ψ_o
120	202.3	0.458	0.493
240	405	0.916	0.952
360	606.5	1.374	1.410
480	810	1.830	1.845
600	1010	2.290	2.315
720	1213	2.746	2.808
840	1416	3.205	3.323
960	1620	3.660	3.736
1080	1820	4.125	4.160

Run No.2

$$F_N = 200.2 \text{ lb.}$$

$$S_N = 14900 \text{ psi}$$

Q_A	S_T	ψ_c	ψ_o
150	252.6	0.573	0.596
300	506	1.145	1.065
450	759	1.720	1.592
600	1010	2.290	2.200
750	1263	2.865	2.740
900	1516	3.440	3.320

3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700

$\Delta = 10000 \text{ bar}$

$\Delta = 5000 \text{ bar}$

Juste

3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700

$\Delta = 75000 \text{ bar}$

$\Delta = 3250 \text{ bar}$

Juste

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$$\Delta = 0.000000$$

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SPECIMEN NO.7

Material: A-4140 Steel

Surface Finish
As machined (lathe)

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01711$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00425 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

				<u>Run No.1</u>	<u>Run No.2</u>
				$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$
				$S_N = 3700 \text{ psi}$	$S_N = 12470 \text{ psi}$
Q_A	S_T	ψ_c	ψ_o	ψ_o	
120	202	0.510	0.367	0.436	
240	404	1.020	0.849	0.895	
300	505	1.274	- - -	- - -	
360	606	1.530	1.410	1.490	
420	706	1.785	- - -	- - -	
480	808	2.040	1.937	2.140	
600	1010	2.546	2.510	2.720	
720	1212	3.057	- - -	3.370	
900	1515	3.820	- - -	- - -	
1020	1718	4.340	- - -	- - -	

RESIDUALS

Least Squares Method

Adjusted R-squared

$$R^2_{adj} = 1 - \frac{(1 - R^2)(n + 1)}{n - k}$$

$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(100 + 1)}{100 - 4}$$

$$R^2_{adj} = 1 - \frac{(0.0001)(101)}{96}$$

$$R^2_{adj} = 1 - \frac{0.00099}{96}$$

$$R^2_{adj} = 1 - 0.0000104167$$

$$R^2_{adj} = 0.9999895833$$

$$R^2_{adj} = 0.9999895833$$

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$$R^2_{adj} = 0.9999895833$$

$$R^2_{adj} = 0.9999895833$$

$$R^2_{adj} = 1 - \frac{(1 - R^2)(n + 1)}{n - k}$$

Adjusted R-squared

Adjusted R-squared

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SPECIMEN NO.7 (continued)

Run No.2				Run No.4			
$F_N = 200.2 \text{ lb.}$				$F_N = 251.2 \text{ lb.}$			
$S_N = 14950 \text{ psi}$				$S_N = 18740 \text{ psi}$			
Q_A	S_T	ψ_c	ψ_o	Q_A	S_T	ψ_c	ψ_o
120	202	0.510	0.435	120	202	0.510	0.435
240	404	1.020	- - -	240	404	1.020	- - -
300	505	1.274	1.237	300	505	1.274	1.363
360	606	1.530	- - -	360	606	1.530	- - -
420	706	1.785	1.753	420	706	1.785	1.850
480	808	2.040	- - -	480	808	2.040	- - -
600	1010	2.546	2.450	600	1010	2.546	2.418
720	1212	3.057	3.092	720	1212	3.057	- - -
900	1515	3.820	4.075	900	1515	3.820	3.940
1020	1718	4.340	- - -	1020	1718	4.340	4.550

SPECIMEN NO. 8

Material: A-4140 Steel

Surface Finish:
No.1 emery paper

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.0177$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_c = 0.00425 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

		<u>Run No.1</u>		<u>Run No.2</u>	
		$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$	
		$S_N = 8700 \text{ psi}$		$S_N = 12470 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o	
150	252.5	0.637	0.618	0.676	
300	505	1.274	1.270	1.330	
450	758	1.910	1.890	1.923	
600	1010	2.546	2.576	2.550	
750	1262	3.185	3.260	3.170	
900	1515	3.820	- - -	- - -	
1050	1770	4.460	- - -	- - -	

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SPECIMEN NO. 8 (continued)

				<u>Run No. 3</u>		<u>Run No. 4</u>	
				$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
				$S_N = 14950 \text{ psi}$		$S_N = 18740 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o		ψ_o	
150	252.5	0.637	0.551	0.585			
300	505	1.274	1.250	1.144			
450	758	1.910	2.042	1.846			
600	1010	2.546	2.520	2.510			
750	1262	3.185	3.164	3.290			
900	1515	3.820	3.890	3.900			
1050	1770	4.460	- - -	4.510			

1000	1330	0.492	0.000	0.000
800	1272	0.480	0.000	0.000
600	1212	0.462	0.000	0.000
400	1152	0.444	0.000	0.000
200	1092	0.426	0.000	0.000
100	1032	0.408	0.000	0.000
50	972	0.390	0.000	0.000
25	912	0.372	0.000	0.000
12.5	852	0.354	0.000	0.000
6.25	792	0.336	0.000	0.000
3.125	732	0.318	0.000	0.000
1.5625	672	0.300	0.000	0.000

$$y^2 = 1.122 \times 10^{-4} \quad y^2 = 1.122 \times 10^{-4}$$

$$y^2 = 1.122 \times 10^{-4} \quad y^2 = 1.122 \times 10^{-4}$$

$$y^2 = 1.122 \times 10^{-4} \quad y^2 = 1.122 \times 10^{-4}$$

1.122 x 10^-4

SPECIMEN NO.8

Run No.7

$$F_N = 201.29 \text{ lb.}$$

$$F_N = 91.3 \text{ kg}$$

$$S_N = 15000 \text{ psi}$$

$$s_n = 1053 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
120	14.2	- - -	- - -	0.0124
240	28.4	- - -	- - -	0.0299
360	42.6	- - -	- - -	0.0373
480	56.8	- - -	- - -	0.0597
600	71.0	- - -	- - -	0.0621
720	85.3	- - -	- - -	0.0746
840	99.5	- - -	- - -	0.0870
960	113.5	0.011	0.86×10^{-6}	0.0995
1080	127.7	0.046	3.59 "	0.1119
1200	142.0	0.057	4.45 "	0.1242
1320	156.2	0.092	7.18 "	0.1367
1440	170.4	0.092	7.18 "	0.1490
1560	184.5	0.138	10.75 "	0.1615
1680	198.7	0.252	19.65 "	0.1740
1800	213.0	0.412	32.15 "	0.1864
1920	227.0	0.803	62.60 "	0.1990
2040	241.0	0.859	67.00 "	0.2113
2160	256.0	1.512	118.0 "	0.2240
2280	270.0	2.660	207.4 "	0.2360
2400	284.0	- - -	- - - -	0.2485

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

	x^0	x^1	x^2	x^3
1000.0	— — —	— — —	1.000	0.000
2000.0	— — —	— — —	1.000	0.000
3000.0	— — —	— — —	1.000	0.000
4000.0	— — —	— — —	1.000	0.000
5000.0	— — —	— — —	1.000	0.000
6000.0	— — —	— — —	1.000	0.000
7000.0	— — —	— — —	1.000	0.000
8000.0	— — —	— — —	1.000	0.000
9000.0	— — —	— — —	1.000	0.000
10000.0	— — —	— — —	1.000	0.000
11000.0	— — —	— — —	1.000	0.000
12000.0	— — —	— — —	1.000	0.000
13000.0	— — —	— — —	1.000	0.000
14000.0	— — —	— — —	1.000	0.000
15000.0	— — —	— — —	1.000	0.000
16000.0	— — —	— — —	1.000	0.000
17000.0	— — —	— — —	1.000	0.000
18000.0	— — —	— — —	1.000	0.000
19000.0	— — —	— — —	1.000	0.000
20000.0	— — —	— — —	1.000	0.000
21000.0	— — —	— — —	1.000	0.000
22000.0	— — —	— — —	1.000	0.000
23000.0	— — —	— — —	1.000	0.000
24000.0	— — —	— — —	1.000	0.000
25000.0	— — —	— — —	1.000	0.000
26000.0	— — —	— — —	1.000	0.000
27000.0	— — —	— — —	1.000	0.000
28000.0	— — —	— — —	1.000	0.000
29000.0	— — —	— — —	1.000	0.000
30000.0	— — —	— — —	1.000	0.000

Run No.8 $F_N = 168.16 \text{ lb.}$ $F_N = 76.4 \text{ kg}$ $S_N = 12540 \text{ psi}$ $s_n = 883 \text{ kg/cm}^2$

Q_A	ϕ_R	θ_R	f	Q_A	ϕ_R	θ_R	f
120	- - -	- - -	0.0149	120	- - -	- - -	0.0213
240	- - -	- - -	0.0298	240	- - -	- - -	0.0426
360	- - -	- - -	0.0446	360	0.138	10.75×10^{-6}	0.0640
480	- - -	- - -	0.0595	480	0.252	"	0.0852
600	0.114	8.89×10^{-6}	0.0745	600	0.653	"	0.1066
720	0.401	31.25	0.0894	720	1.042	"	0.1280
840	0.481	37.50	0.1042	840	1.820	"	0.1492
960	0.905	70.60	0.1190	960	3.240	"	0.1705
1080	0.974	76.00	0.1340	1080	- - -	- - -	0.1916
1200	0.940	73.35	0.1487				
1320	1.132	88.30	0.1636				
1440	1.317	102.6	0.1786				
1560	1.545	120.5	0.1935				
1680	2.395	186.6	0.2085				
1800	2.575	200.8	0.2232				
1920	2.740	214.0	0.2380				
2040	3.045	237.5	0.2530				
2160	5.440	424.0	0.2680				
2280	- - -	- - -	0.2830				

Run No.9 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 8760 \text{ psi}$ $s_n = 616 \text{ kg/cm}^2$

SPECIMEN NO.8 (continued)

Run No.10

$$F_N = 64.78 \text{ lb.}$$

$$F_N = 29.4 \text{ kg}$$

$$S_N = 4835 \text{ psi}$$

$$s_n = 340 \text{ kg/cm}^2$$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0386
240	0.172	13.40×10^{-6}	0.0773
360	0.836	65.20 "	0.1160
480	8.850	690.0 "	0.1545
600	- - -	- - -	0.1930

(Continued) R. M. H. H. H. H. H.

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1	2	3	4
1911-1912	1911-1912	1911-1912	1911-1912
1911-1912	1911-1912	1911-1912	1911-1912
1911-1912	1911-1912	1911-1912	1911-1912
1911-1912	1911-1912	1911-1912	1911-1912
1911-1912	1911-1912	1911-1912	1911-1912

SPECIMEN NO.9

Material: A-4140 Steel

Surface Finish:
2/0 paper

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01711$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01342}$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_c = 0.00425 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

<u>Run No.1</u>		<u>Run No.2</u>	
$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$	
$S_N = 8700 \text{ psi}$		$S_N = 12470 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o
150	252.5	0.637	0.425
300	505	1.274	1.240
450	758	1.910	1.800
600	1010	2.546	2.363
750	1262	3.185	2.910
900	1515	3.820	3.650
1050	1770	4.460	4.410

SPECIMEN NO. 9 (continued)

		<u>Run No. 3</u>		<u>Run No. 4</u>	
		$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
		$S_N = 14950 \text{ psi}$		$S_N = 18740 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o	
150	252.5	0.637	0.551	0.768	
300	505	1.274	1.390	1.240	
450	758	1.910	1.893	2.009	
600	1010	2.546	2.480	2.560	
750	1262	3.185	3.020	3.155	
900	1515	3.820	3.760	- - -	
1050	1770	4.460	- - -	- - -	

Material: 2S Aluminum

Control Specimen:
(without interface)

$$D_0 = 0.2365''$$

$$D_1 = 0.191''$$

$$7786.0 = 7$$

$$D_0^2 - D_1^2 = 0.01945$$

$$D_4 - D_4^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01526$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_0}{D_0 - D_i} \times Q_A$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times C_A}{(D_o^4 - D_i^4) \times L^3}$$

$$L_s = 3.7 \times 10^6 \text{ psi}$$

$$= 0.01145 \times 10^4$$

77110.0 =

ψ_R = Residual Twist. Sight edges on indicator arms failed to return to zero index on removal of torque. ψ_R is residual twist remaining in specimen after removal of torque.

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SPECIMEN NO.11

Material: Copper

Control Specimen:
(without interface)

$$D_o = 0.2368''$$

$$D_i = 0.191''$$

$$L = 1.01563''$$

$$D_o^2 - D_i^2 = 0.01959$$

$$D_o^4 - D_i^4 = 0.001814$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01537$$

$$S_N = \frac{F_N}{0.01537} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} Q_A$$

$$S_T = 1.464 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$E_s = 6.0 \times 10^6 \text{ psi}$$

$$\psi_c = 0.00722 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 200 \text{ lb.}$$

$$S_N = 13020 \text{ psi}$$

$$Q_A$$

$$\psi_o$$

$$S_T$$

$$\psi_o$$

$$\psi_R$$

$$Q_A$$

$$\psi_R$$

$$Q_A$$

$$\psi_R$$

Run No.2

$$F_N = 250 \text{ lb.}$$

$$S_N = 16270 \text{ psi}$$

$$Q_A$$

$$\psi_o$$

$$S_T$$

$$\psi_o$$

$$\psi_R$$

$$Q_A$$

$$\psi_R$$

$$Q_A$$

$$\psi_R$$

Run No.3

$$F_N = 200 \text{ lb.}$$

$$S_N = 13020 \text{ psi}$$

$$Q_A$$

$$\psi_o$$

$$S_T$$

$$\psi_o$$

$$\psi_R$$

$$Q_A$$

$$\psi_R$$

$$Q_A$$

$$\psi_R$$

SPECIMEN NO.12

Run No.1

$$F_N = 31.86 \text{ lb.}$$

$$F_N = 14.4 \text{ kg}$$

$$S_N = 2375 \text{ psi}$$

$$s_n = 167 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
120	14.2	- - -	- - -	0.0785
240	28.4	0.046	3.59×10^{-6}	0.1570
360	42.6	0.149	11.60 "	0.2358
480	56.8	0.825	64.40 "	0.3140
600	71.0	- - -	- - -	0.3930
720	85.3			
840	99.5			
960	113.5			
1080	127.7			
1200	142.0			
1320	156.2			
1440	170.4			
1560	184.5			
1680	198.7			
1800	213.0			

Material: A-4140 Steel

Surface Finish: 4/0 paper

MECHANICAL PROPERTIES

TEST DATA

1. Tensile Strength

2. Yield Strength

3. Elongation

4. Reduction of Area

Test No.	Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (%)	Reduction of Area (%)
1001	42.5	68.0	25.0	45.0
1002	43.0	69.0	26.0	46.0
1003	42.0	67.0	24.0	44.0
1004	43.5	70.0	27.0	47.0
1005	42.8	68.5	25.5	45.5
1006	43.2	69.5	26.5	46.5
1007	42.2	67.5	24.5	44.5
1008	43.8	70.5	27.5	47.5
1009	42.5	68.0	25.0	45.0
1010	43.0	69.0	26.0	46.0
1011	42.0	67.0	24.0	44.0
1012	43.5	70.0	27.0	47.0
1013	42.8	68.5	25.5	45.5
1014	43.2	69.5	26.5	46.5
1015	42.2	67.5	24.5	44.5
1016	43.8	70.5	27.5	47.5
1017	42.5	68.0	25.0	45.0
1018	43.0	69.0	26.0	46.0
1019	42.0	67.0	24.0	44.0
1020	43.5	70.0	27.0	47.0

Material: A-36 Steel
Surface Finish: 400 Paper

SPECIMEN NO.12 (continued)

Run No.2 $F_N = 53.8 \text{ lb.}$ $F_N = 24.2 \text{ kg}$ $S_N = 3980 \text{ psi}$ $s_n = 280 \text{ kg/cm}^2$

Q_A	ψ_R	σ_R	f
120	0.114	8.89×10^{-6}	0.0469
240	0.184	14.34	0.0938
360	0.321	25.05	0.1406
480	0.860	67.15	0.1875
600	2.580	201.3	0.2344
720	3.085	240.6	0.2814
840	- - -	- - -	0.3280

Run No.3 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 8760 \text{ psi}$ $s_n = 616 \text{ kg/cm}^2$

Q_A	ψ_R	σ_R	f
120	- - -	- - -	0.0213
240	- - -	- - -	0.0426
360	0.011	0.86×10^{-6}	0.0640
480	0.046	3.59	0.0862
600	0.184	14.34	0.1066
720	0.665	51.90	0.1280
840	0.688	53.65	0.1492
960	0.872	68.00	0.1705
1080	1.053	82.20	0.1916
1200	1.144	89.30	0.2130
1320	1.707	133.0	0.2340
1440	2.096	163.3	0.2555
1560	3.060	238.6	0.2768
1680	7.550	589.0	0.2980
1800	- - -	- - -	0.3190

(continued) 31-bit addresses

Level 000

7th 2A, 11C = 0

6th 5, 10 = 0

5th 2000 = 0

4th 100 000 = 0

3

2nd 000 = 0

1100.0

9000.0

8000.0

7000.0

6000.0

5000.0

4000.0

3000.0

2000.0

1000.0

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Level 001

4th 0000 = 0

3rd 000 = 0

2nd 0000 = 0

1st 0000 000 = 0

2

0th 0000 = 0

0000.0

8000.0

7000.0

6000.0

5000.0

4000.0

3000.0

2000.0

1000.0

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SPECIMEN NO.13

Run No.1

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11170 \text{ psi}$$

$$s_n = 785 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
60	6.3	- - -	- - -	0.0074
120	12.6	0.080	6.34×10^{-6}	0.0147
180	18.9	0.103	8.15 "	0.0220
240	25.2	0.114	9.04 "	0.0294
300	31.5	- - -	- - -	0.0367

Run No.5

$$F_N = 117.41 \text{ lb.}$$

$$F_N = 53.3 \text{ kg}$$

$$S_N = 7800 \text{ psi}$$

$$s_n = 548 \text{ kg/cm}^2$$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0211
240	0.023	1.81×10^{-6}	0.0421
360	0.126	9.95 "	0.0632
480	0.149	11.76 "	0.0842
600	0.183	14.45 "	0.1052
720	0.298	23.50 "	0.1264
840	- - -	- - -	0.1475

Line 1000000

Line 1000000

Line 1000000

Line 1000000

Line 1000000

Line 1000000

	μ^0	μ^1	μ^2	μ^3
1000.0	- - -	- - -	1.0	0.0
2000.0	0.0	0.0	0.0	0.0
3000.0	0.0	0.0	0.0	0.0
4000.0	0.0	0.0	0.0	0.0
5000.0	- - -	- - -	1.0	0.0

Line 1000000

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Line 1000000

	μ^0	μ^1	μ^2
1000.0	- - -	- - -	0.0
2000.0	0.0	0.0	0.0
3000.0	0.0	0.0	0.0
4000.0	0.0	0.0	0.0
5000.0	0.0	0.0	0.0
6000.0	0.0	0.0	0.0
7000.0	- - -	- - -	0.0

SPECIMEN NO.13 (continued)

Run No.2 $F_N = 201.29 \text{ lb.}$ $F_N = 91.3 \text{ kg}$ $S_N = 13360 \text{ psi}$ $s_n = 939 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f	Q_A	ψ_R	θ_R	f
60	-	-	0.00615	120	-	-	0.0098
120	-	-	0.0123	240	-	-	0.0197
180	0.149	11.76×10^{-6}	0.0184	360	0.114	9.00×10^{-6}	0.0295
240	0.069	5.42	0.0246	480	0.046	3.62	0.0394
300	0.149	11.76	0.0308	600	0.183	14.45	0.0493
360	0.137	10.85	0.0369	720	0.435	34.40	0.0640
420	0.309	24.40	0.0430	840	0.618	48.80	0.0690
480	0.275	21.72	0.0491	960	-	-	-
540	0.286	22.60	0.0553				
600	0.367	29.00	0.0615				
660	0.458	36.20	0.0676				
720	0.435	34.40	0.0737				
780	0.435	34.40	0.0800				
840	0.446	35.22	0.0860				
960	-	-	-				

Run No.3 $F_N = 251 \text{ lb.}$ $F_N = 114.0 \text{ kg}$ $S_N = 16700 \text{ psi}$ $s_n = 1172 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	-	-	0.0098
240	-	-	0.0197
360	0.114	9.00×10^{-6}	0.0295
480	0.046	"	0.0394
600	0.183	"	0.0493
720	0.435	"	0.0640
840	0.618	"	0.0690
960	-	-	-

(Name/Date) Class Number

Exercises

$$\sin 30^\circ = \frac{1}{2}$$

$$\sin 45^\circ = \frac{\sqrt{2}}{2}$$

$$\sin 60^\circ = \frac{\sqrt{3}}{2}$$

$$\cos 30^\circ = \frac{\sqrt{3}}{2}$$

$$\cos 45^\circ = \frac{\sqrt{2}}{2}$$

$$\cos 60^\circ = \frac{1}{2}$$

$$\tan 30^\circ = \frac{1}{\sqrt{3}}$$

$$\tan 45^\circ = 1$$

$$\tan 60^\circ = \sqrt{3}$$

$$\cot 30^\circ = \sqrt{3}$$

$$\cot 45^\circ = 1$$

$$\cot 60^\circ = \frac{1}{\sqrt{3}}$$

$$\sec 30^\circ = \frac{2}{\sqrt{3}}$$

$$\sec 45^\circ = \sqrt{2}$$

$$\sec 60^\circ = 2$$

$$\csc 30^\circ = 2$$

$$\csc 45^\circ = \sqrt{2}$$

Exercises

$$\sin 30^\circ = \frac{1}{2}$$

$$\sin 45^\circ = \frac{\sqrt{2}}{2}$$

$$\sin 60^\circ = \frac{\sqrt{3}}{2}$$

$$\cos 30^\circ = \frac{\sqrt{3}}{2}$$

$$\cos 45^\circ = \frac{\sqrt{2}}{2}$$

$$\cos 60^\circ = \frac{1}{2}$$

$$\tan 30^\circ = \frac{1}{\sqrt{3}}$$

$$\tan 45^\circ = 1$$

$$\tan 60^\circ = \sqrt{3}$$

$$\cot 30^\circ = \sqrt{3}$$

$$\cot 45^\circ = 1$$

$$\cot 60^\circ = \frac{1}{\sqrt{3}}$$

$$\sec 30^\circ = \frac{2}{\sqrt{3}}$$

$$\sec 45^\circ = \sqrt{2}$$

$$\sec 60^\circ = 2$$

$$\csc 30^\circ = 2$$

$$\csc 45^\circ = \sqrt{2}$$

SPECIMEN NO.13 (continued)

Run No.6 $P_N = 168.16 \text{ lb.}$ $P_N = 76.4 \text{ kg}$ $S_N = 11170 \text{ psi}$ $s_n = 785 \text{ kg/cm}^2$

Q_A	ϕ_R	θ_R	f
120	- - -	- - -	0.0147
240	0.092	7.24×10^{-6}	0.0294
360	0.080	6.33 "	0.0441
480	0.057	4.52 "	0.0588
600	0.092	7.24 "	0.0735
720	0.195	15.35 "	0.0882
840	0.481	38.00 "	0.1028
960	0.722	57.00 "	0.1175
1080	0.929	73.30 "	0.1320
1200	- - -	- - -	0.1470

Run No.7 $P_N = 201.29 \text{ lb.}$ $P_N = 91.3 \text{ kg}$ $S_N = 13360 \text{ psi}$ $s_n = 939 \text{ kg/cm}^2$

Q_A	ϕ_R	θ_R	f
120	- - -	- - -	0.0123
240	0.011	0.90×10^{-6}	0.0246
360	0.092	7.24 "	0.0369
480	0.172	13.56 "	0.0491
600	0.149	11.76 "	0.0615
720	0.218	17.15 "	0.0737
840	0.321	25.30 "	0.0860
960	0.458	36.10 "	0.0983
1080	0.493	38.90 "	0.1105
1200	0.550	43.30 "	0.1228
1320	0.825	65.10 "	0.1350
1440	2.120	167.0 "	0.1473
1560	2.820	222.4 "	0.1596
1680	- - -	- - -	0.1720

(Continued) E-28 (continued)

Calculated

$$\Delta H_{\text{calculated}} = \frac{1}{2} \Delta H_{\text{observed}}$$

$$\Delta H_{\text{calculated}} = \frac{1}{2} \Delta H_{\text{observed}}$$

$$\Delta H_{\text{calculated}} = \frac{1}{2} \Delta H_{\text{observed}}$$

$$\Delta H_{\text{calculated}} = \frac{1}{2} \Delta H_{\text{observed}}$$

Observed

$$\Delta H_{\text{observed}} = \frac{1}{2} \Delta H_{\text{calculated}}$$

$$\Delta H_{\text{observed}} = \frac{1}{2} \Delta H_{\text{calculated}}$$

$$\Delta H_{\text{observed}} = \frac{1}{2} \Delta H_{\text{calculated}}$$

$$\Delta H_{\text{observed}} = \frac{1}{2} \Delta H_{\text{calculated}}$$

1	$\Delta H_{\text{calculated}}$	$\Delta H_{\text{observed}}$	$\Delta H_{\text{calculated}}$	$\Delta H_{\text{observed}}$
1210.0	1210.0	1210.0	1210.0	1210.0
1220.0	1220.0	1220.0	1220.0	1220.0
1230.0	1230.0	1230.0	1230.0	1230.0
1240.0	1240.0	1240.0	1240.0	1240.0
1250.0	1250.0	1250.0	1250.0	1250.0
1260.0	1260.0	1260.0	1260.0	1260.0
1270.0	1270.0	1270.0	1270.0	1270.0
1280.0	1280.0	1280.0	1280.0	1280.0
1290.0	1290.0	1290.0	1290.0	1290.0
1300.0	1300.0	1300.0	1300.0	1300.0
1310.0	1310.0	1310.0	1310.0	1310.0
1320.0	1320.0	1320.0	1320.0	1320.0
1330.0	1330.0	1330.0	1330.0	1330.0
1340.0	1340.0	1340.0	1340.0	1340.0
1350.0	1350.0	1350.0	1350.0	1350.0
1360.0	1360.0	1360.0	1360.0	1360.0
1370.0	1370.0	1370.0	1370.0	1370.0
1380.0	1380.0	1380.0	1380.0	1380.0
1390.0	1390.0	1390.0	1390.0	1390.0
1400.0	1400.0	1400.0	1400.0	1400.0
1410.0	1410.0	1410.0	1410.0	1410.0
1420.0	1420.0	1420.0	1420.0	1420.0
1430.0	1430.0	1430.0	1430.0	1430.0
1440.0	1440.0	1440.0	1440.0	1440.0
1450.0	1450.0	1450.0	1450.0	1450.0
1460.0	1460.0	1460.0	1460.0	1460.0
1470.0	1470.0	1470.0	1470.0	1470.0
1480.0	1480.0	1480.0	1480.0	1480.0
1490.0	1490.0	1490.0	1490.0	1490.0
1500.0	1500.0	1500.0	1500.0	1500.0

SPECIMEN NO.14

Material: Copper

Surface Finish: 2/o Paper

$$D_o = 0.2359"$$

$$D_i = 0.191"$$

$$L = 1.000"$$

$$S_N = \frac{F_N}{0.01505} \text{ psi}$$

$$S_T = 1.495 \times Q_A \text{ psi}$$

$$\psi_c = 0.00708 \times Q_A$$

$$E_s = 6.0 \times 10^6 \text{ psi}$$

$$\psi_o = 0.01144 \psi_s$$

<u>Run No.1</u>		<u>Run No.2</u>	
$F_N = 64.8 \text{ lb.}$		$F_N = 117.4 \text{ lb.}$	
$S_N = 4300 \text{ psi}$		$S_N = 7800 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o
120	180	0.850	0.756
240	359	1.700	1.560
360	539	2.550	2.510
480	719	3.400	3.480
600	900	4.250	4.500
720	1076	5.100	5.730
840	1257	5.950	5.970
960	1436	6.800	
1080	1614	7.650	

SPECIMEN NO.14 (continued)

<u>Run No.3</u>				<u>Run No.4</u>				<u>Run No.5</u>			
$F_N = 168.2 \text{ lb.}$				$F_N = 201.3 \text{ lb.}$				$F_N = 231.68 \text{ lb.}$			
$S_N = 11170 \text{ psi}$				$S_N = 13360 \text{ psi}$				$S_N = 15400 \text{ psi}$			
Q_A	S_T	ψ_c	ψ_o	Q_A	ψ_o	Q_A	ψ_o	Q_A	ψ_o	Q_A	ψ_o
120	180	0.850	0.733	120	0.780	120	0.882	120	0.882	120	0.882
240	359	1.700	1.525	240	1.696	240	1.294	240	1.294	240	1.294
360	539	2.550	2.350	360	2.570	360	2.610	360	2.610	360	2.610
480	719	3.400	3.080	480	3.475	480	3.540	480	3.540	480	3.540
600	900	4.250	4.040	600	4.290	600	4.380	600	4.380	600	4.380
720	1076	5.100	4.940	720	5.360	720	5.333	720	5.333	720	5.333
840	1257	5.950	5.740	840	6.310	840	6.230	840	6.230	840	6.230
960	1436	6.800	6.720	960	7.230	960	7.250	960	7.250	960	7.250
1080	1614	7.650	-	-	-	-	-	-	-	-	-

- - - - - off scope - - - - -

TABLE 1. SUMMARY OF DATA

Run			Time			Temperature			Pressure		
Run	Time	Temp	Time	Temp	Time	Time	Temp	Time	Time	Temp	Time
1	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
2	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
3	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
4	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
6	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
7	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
8	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
10	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

SPECIMEN NO.14

Run No.1

$$F_N = 64.78 \text{ lb.}$$

$$F_N = 29.4 \text{ kg}$$

$$S_N = 4300 \text{ psi}$$

$$s_n = 302 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	ϕ_R	f
120	12.6	- - -	- - -	0.0382
240	25.2	0.183	14.46×10^{-6}	0.0763
360	37.8	0.298	23.50 "	0.1144
480	50.5	0.505	39.88 "	0.1526
600	63.1	3.310	261.5 "	0.1910
720	75.6	- - -	- - -	0.2290
840	88.4			
960	101.0			
1080	113.6			
1200	126.1			
1320	138.9			
1440	151.2			
1560	164.0			
1680	176.6			
1800	189.0			
1920	201.5			
2040	214.2			
2160	226.8			
2280	239.5			
2400	252.0			
2520	264.0			

SPECIMEN NO.14 (continued)

Run No.2 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 7800 \text{ psi}$ $s_n = 548 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0211
240	0.057	4.50×10^{-6}	0.0421
360	0.184	14.50	0.0632
480	0.378	29.80	0.0842
600	0.653	51.50	0.1052
720	1.032	81.50	0.1264
840	1.420	112.0	0.1475
960	3.370	294.3	0.1683
1080	10.000	790.0	0.1893
1200	- - -	- - -	0.2100

Run No.3 $F_N = 168.16 \text{ lb.}$ $F_N = 764 \text{ kg}$ $S_N = 11170 \text{ psi}$ $s_n = 785 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0147
240	- - -	- - -	0.0294
360	- - -	- - -	0.0441
480	- - -	- - -	0.0588
600	0.057	4.50×10^{-6}	0.0735
720	0.149	11.76	0.0882
840	0.172	13.56	0.1028
960	0.241	19.00	0.1175
1080	0.355	28.00	0.1320
1200	0.390	30.78	0.1470
1320	0.424	33.24	0.1616
1440	0.734	57.90	0.1764
1560	- - -	- - -	0.1910

East 200

101 21.000 x 10³

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103 21.000 x 10³

104 21.000 x 10³

East 200

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102 21.000 x 10³

103 21.000 x 10³

104 21.000 x 10³

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Run No.4 $F_N = 201.29 \text{ lb.}$ $F_N = 91.3 \text{ kg}$ $S_N = 13360 \text{ psi}$ $s_n = 939 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f	Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0123	120	- - -	- - -	0.0107
240	0.184	14.50×10^{-6}	0.0246	240	0.160	12.62×10^{-6}	0.0214
360	0.264	"	0.0369	360	0.321	"	0.0320
480	0.435	"	0.0491	480	0.424	"	0.0427
600	0.550	"	0.0615	600	0.493	"	0.0535
720	0.723	"	0.0737	720	0.619	"	0.0640
840	0.769	"	0.0860	840	0.756	"	0.0748
960	0.906	"	0.0983	960	0.974	"	0.0855
1080	1.007	"	0.1105	1080	0.962	"	0.0962
1200	1.087	"	0.1228	1200	1.100	"	0.1069
1320	1.363	"	0.1350	1320	1.340	"	0.1175
1440	1.546	"	0.1473	1440	1.350	"	0.1280
1560	2.040	"	0.1596	1560	1.593	"	0.1390
1680	2.222	"	0.1720	1680	1.775	"	0.1495
1800	2.500	"	0.1845	1800	1.890	"	0.1600
1920	2.960	"	0.1966	1920	2.060	"	0.1708
2040	- - -	- - -	0.2090	2040	2.325	"	0.1815

Run No.5 $F_N = 231.68 \text{ lb.}$ $F_N = 105.0 \text{ kg}$ $S_N = 15400 \text{ psi}$ $s_n = 1080 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0107
240	0.160	12.62×10^{-6}	0.0214
360	0.321	"	0.0320
480	0.424	"	0.0427
600	0.493	"	0.0535
720	0.619	"	0.0640
840	0.756	"	0.0748
960	0.974	"	0.0855
1080	0.962	"	0.0962
1200	1.100	"	0.1069
1320	1.340	"	0.1175
1440	1.350	"	0.1280
1560	1.593	"	0.1390
1680	1.775	"	0.1495
1800	1.890	"	0.1600
1920	2.060	"	0.1708
2040	2.325	"	0.1815
2160	2.690	"	0.1920
2280	2.990	"	0.2030
2400	3.350	"	0.2135

Cell 1001

$$-d^2 \text{ 05.125} = d^2$$

$$d^2 = 104.0 \text{ 10}$$

$$d^2 = 1000 \text{ 10}$$

$$d^2 = 1000 \text{ 10}$$

Cell 1002

$$-d^2 \text{ 05.125} = d^2$$

$$d^2 = 104.0 \text{ 10}$$

$$d^2 = 1000 \text{ 10}$$

$$d^2 = 1000 \text{ 10}$$

1

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d^2

d^2

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d^2

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SPECIMEN NO.15

Run No.1

$$F_N = 201.29 \text{ lb.}$$

$$F_N = 91.3 \text{ kg}$$

$$S_N = 13360 \text{ psi}$$

$$s_n = 939 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
120	12.6	- - -	- - -	0.0123
240	25.2	- - -	- - -	0.0246
360	37.8	0.069	5.42×10^{-6}	0.0368
480	50.5	- - -	- - -	0.0491
600	63.1	0.161	12.90 "	0.0614
720	75.6	0.011	0.90 "	0.0736
840	88.4	0.057	4.50 "	0.0860
960	101.0	0.034	2.68 "	0.0982
1080	113.6	0.069	5.42 "	0.1104
1200	126.1	0.126	9.95 "	0.1226
1320	138.9	0.252	19.90 "	0.1350
1440	151.2	0.355	28.00 "	0.1472
1560	164.0	0.458	36.20 "	0.1595
1680	176.6	0.653	51.55 "	0.1716
1800	189.0	0.734	57.90 "	0.1840

Material: Copper

Surface Finish: 4/0 paper

T	δ^0	δ^B	δ^A	N^2
2550.0	— — —	— — —	0.12	052
2555.0	— — —	— — —	0.15	045
2560.0	$\delta = 0.1 = 12.7$	000.0	0.17	041
2565.0	— — —	— — —	0.20	041
2570.0	" 00.10	141.0	0.22	005
2575.0	" 00.7	150.0	0.24	037
2580.0	" 01.1	150.0	0.25	038
2585.0	" 01.2	150.0	0.101	039
2590.0	" 01.3	000.0	0.11	080
2595.0	" 01.4	071.0	0.101	005
2600.0	" 01.01	012.0	0.091	070
2605.0	" 00.80	117.0	0.101	011
2610.0	" 00.60	011.0	0.101	043
2615.0	" 00.32	110.0	0.071	080
2620.0	" 00.12	100.0	0.031	000

Waterfall : Copper

Surface Finish: 400 Paper

SPECIMEN NO.15 (continued)

Run No.2 $F_N = 168.16 \text{ lb.}$ $F_N = 76.4 \text{ kg}$ $S_N = 11170 \text{ psi}$ $s_n = 785 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0147
240	0.011	0.90×10^{-6}	0.0294
360	0.023	1.81 "	0.0441
480	- - -	- - -	0.0588
600	0.011	0.90 "	0.0735
720	0.034	2.68 "	0.0882
840	0.034	2.68 "	0.1028
960	0.069	5.42 "	0.1175
1080	0.103	8.15 "	0.1320
1200	0.194	15.30 "	0.1470
1320	0.218	17.20 "	0.1615
1440	0.229	18.09 "	0.1762
1560	0.309	24.40 "	0.1910
1680	0.619	48.85 "	0.2060
1800	- - -	- - -	0.2203

Run No.3 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 7800 \text{ psi}$ $s_n = 548 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0211
240	- - -	- - -	0.0421
360	- - -	- - -	0.0632
480	0.023	1.81×10^{-6}	0.0842
600	0.126	9.95 "	0.1052
720	0.149	11.76 "	0.1265
840	0.229	18.09 "	0.1475
960	- - -	- - -	0.1686

[illegible]

(continued) 21.06 2005

SPECIMEN NO.15 (continued)

Run No.4

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11170 \text{ psi}$$

$$s_n = 785 \text{ kg/cm}^2$$

C_A	ϕ_R	θ_R	f
120	- - -	- - -	0.0147
240	0.103	8.15×10^{-6}	0.0294
360	0.149	11.76 "	0.0441
480	0.195	15.40 "	0.0588
600	0.344	27.15 "	0.0735
720	0.413	32.60 "	0.0882
840	0.768	60.65 "	0.1028
960	1.134	89.50 "	0.1175
1080	- - -	- - -	0.1320

[Asteroid 1900-1909]

Asteroid 1900-1909

$$1900.0 - 1901.0 = 1.0$$

$$1901.0 - 1902.0 = 1.0$$

$$1902.0 - 1903.0 = 1.0$$

$$1903.0 - 1904.0 = 1.0$$

1900.0	1901.0	1902.0	1903.0
1900.0	1901.0	1902.0	1903.0
1904.0	1905.0	1906.0	1907.0
1908.0	1909.0	1910.0	1911.0
1912.0	1913.0	1914.0	1915.0
1916.0	1917.0	1918.0	1919.0
1920.0	1921.0	1922.0	1923.0
1924.0	1925.0	1926.0	1927.0
1930.0	1931.0	1932.0	1933.0
1934.0	1935.0	1936.0	1937.0
1940.0	1941.0	1942.0	1943.0
1944.0	1945.0	1946.0	1947.0
1950.0	1951.0	1952.0	1953.0

SPECIMEN NO.15 (continued)

Run No.5

$P_N = 117.41 \text{ lb.}$
 $P_N = 53.3 \text{ kg}$
 $S_N = 7800 \text{ psi}$
 $s_n = 548 \text{ kg/cm}^2$

Q_A	ϕ_R	θ_R	f
120	0.080	6.34×10^{-6}	0.0211
240	0.321	25.30	0.0421
360	0.596	47.10	0.0632
480	1.396	110.0	0.0842
600	- - -	- - -	0.1052

Run No.7

$P_N = 64.78 \text{ lb.}$
 $P_N = 29.4 \text{ kg}$
 $S_N = 4300 \text{ psi}$
 $s_n = 302 \text{ kg/cm}^2$

ϕ_R	θ_R	f
0.092	7.24×10^{-6}	0.0382
0.241	19.04	0.0763
0.940	74.20	0.1144
8.50	671.0	0.1526

(continued) 21-28 minutes

Left Hand

$$\text{all } 20.00 = 2^4$$

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$$\text{all } 20.00 = 2^4$$

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Right Hand

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$$\text{all } 20.00 = 2^4$$

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$$\text{all } 20.00 = 2^4$$

$$\text{all } 20.00 = 2^4$$

2^4	2^3	2^2	2^1	2^0	2^0	2^0	2^0
011	000.0	000.0	000.0	000.0	000.0	000.0	000.0
010	000.0	000.0	000.0	000.0	000.0	000.0	000.0
001	000.0	000.0	000.0	000.0	000.0	000.0	000.0
000	000.0	000.0	000.0	000.0	000.0	000.0	000.0

SPECIMEN NO.16

Material: 2S Aluminum

Surface Finish: No. 1 Paper

Run No.1

$$F_N = 764 \text{ kg}$$

$$s_n = 772 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f	ψ_o
12	1.24	0.458	30.10×10^{-6}	0.0015	0.183
30	3.11	0.138	10.87 "	0.0037	0.413
60	6.23	0.138	10.87 "	0.0073	0.836
90	9.33	0.275	21.65 "	0.0119	1.064
120	12.43	0.321	25.30 "	0.0147	1.443
150	15.55	0.424	33.40 "	0.0183	1.866
180	18.65	0.596	47.00 "	0.0220	2.085
210	21.80	0.699	55.10 "	0.0256	2.462
240	24.90	0.630	49.65 "	0.0293	2.820
270	28.00	0.722	57.00 "	0.0330	3.130
300	31.15	0.756	59.60 "	0.0367	3.450
330	34.25	0.814	64.15 "	0.0403	3.930
360	37.35	0.836	65.95 "	0.0440	4.220
390	40.50	0.956	75.40 "	0.0476	4.530
420	43.65	0.985	77.60 "	0.0514	4.810

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№	№	№	№	№	№
1	1	1	1	1	1
2	2	2	2	2	2
3	3	3	3	3	3
4	4	4	4	4	4
5	5	5	5	5	5
6	6	6	6	6	6
7	7	7	7	7	7
8	8	8	8	8	8
9	9	9	9	9	9
10	10	10	10	10	10
11	11	11	11	11	11
12	12	12	12	12	12
13	13	13	13	13	13
14	14	14	14	14	14
15	15	15	15	15	15
16	16	16	16	16	16
17	17	17	17	17	17
18	18	18	18	18	18
19	19	19	19	19	19
20	20	20	20	20	20
21	21	21	21	21	21
22	22	22	22	22	22
23	23	23	23	23	23
24	24	24	24	24	24
25	25	25	25	25	25
26	26	26	26	26	26
27	27	27	27	27	27
28	28	28	28	28	28
29	29	29	29	29	29
30	30	30	30	30	30
31	31	31	31	31	31
32	32	32	32	32	32
33	33	33	33	33	33
34	34	34	34	34	34
35	35	35	35	35	35
36	36	36	36	36	36
37	37	37	37	37	37
38	38	38	38	38	38
39	39	39	39	39	39
40	40	40	40	40	40
41	41	41	41	41	41
42	42	42	42	42	42
43	43	43	43	43	43
44	44	44	44	44	44
45	45	45	45	45	45
46	46	46	46	46	46
47	47	47	47	47	47
48	48	48	48	48	48
49	49	49	49	49	49
50	50	50	50	50	50
51	51	51	51	51	51
52	52	52	52	52	52
53	53	53	53	53	53
54	54	54	54	54	54
55	55	55	55	55	55
56	56	56	56	56	56
57	57	57	57	57	57
58	58	58	58	58	58
59	59	59	59	59	59
60	60	60	60	60	60
61	61	61	61	61	61
62	62	62	62	62	62
63	63	63	63	63	63
64	64	64	64	64	64
65	65	65	65	65	65
66	66	66	66	66	66
67	67	67	67	67	67
68	68	68	68	68	68
69	69	69	69	69	69
70	70	70	70	70	70
71	71	71	71	71	71
72	72	72	72	72	72
73	73	73	73	73	73
74	74	74	74	74	74
75	75	75	75	75	75

SPECIMEN NO.16 (continued)

Material: 2S Aluminum

Surface Finish: No. 1 Paper

Run No.2

$$F_N = 91.3 \text{ kg}$$

$$s_n = 928 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f	ψ_o
12	1.24	- - -	- - -	0.0012	- - -
30	3.11	- - -	- - -	0.0031	0.378
60	6.23	- - -	- - -	0.0061	0.596
90	9.33	0.114	9.00×10^{-6}	0.0092	1.030
120	12.43	0.138	10.87 "	0.0123	1.283
150	15.55	0.183	14.42 "	0.0153	1.640
180	18.65	0.138	10.87 "	0.0184	1.970
210	21.80	0.206	16.24 "	0.0214	2.220
240	24.90	0.252	19.86 "	0.0245	2.625
270	28.00	0.283	22.30 "	0.0276	2.980
300	31.15	0.367	28.90 "	0.0307	3.240
330	34.25				

1997年12月 第2期 总第102期

[illegible]

APPENDIX C
SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

Calculated angle of twist of specimen without interface = ψ_o

$$\psi = \frac{T_A L}{E_s J} \text{ radians} \quad (1)$$

$$J = \frac{\pi(D_o^4 - D_i^4)}{32} \quad (2)$$

$$\psi_c = \frac{180}{\pi} \times 60 \times \psi \quad (3)$$

$$T_A = 2.205 \times 10^{-3} Q_A \quad (4)$$

Substituting (2), (3), and (4) in (1) gives

$$\psi_c = \frac{77.3 \times Q_A \times L}{(D_o^4 - D_i^4) \times E_s} \text{ Min.arc.} \quad (5)$$

Maximum tangential stress = S_T .

$$S_T = \frac{16 T_A D_o}{\pi(D_o^4 - D_i^4)} \quad (6)$$

Substituting (4) in (6) gives

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q \text{ psi} \quad (7)$$

Observed angle of twist of specimen = ψ_o .

With 10 x objective calibration with micrometer stage shows one drum unit of optical micrometer represents 0.00004101" on indicator.

ψ_s drum units = 0.00004101 x ψ_s inches on indicator.

$$\psi_o = \frac{\psi_s}{R} \text{ radians} \times \frac{180}{\pi} \frac{\text{degrees}}{\text{radians}} \times 60 \frac{\text{min.}}{\text{degree}} .$$

$$\psi_o = \frac{\psi_s (0.00004101)}{12.33} \times 3440$$

$$\psi_o = 0.01144 \psi_s \quad (8)$$

Coefficient of friction = f .

$$T = \frac{1}{3} f \times F_N \frac{(D_o^3 - D_1^3)}{(D_o^2 - D_1^2)} \quad (9)$$

T = torque of friction about axis of shaft.

Substituting (4) in (9) gives

$$f = \frac{Q_A}{F_N} \times 6.615 \times 10^{-3} \times \frac{(D_o^2 - D_1^2)}{(D_o^3 - D_1^3)}$$

4. Given ratio = 0.000001 = 1/1000000 = 1/10^6

$$\frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

$$\frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

$$(10) \quad \frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

Coefficient of friction = 1.

$$(11) \quad \frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

1. = average of friction about axis of shaft.

Substituting (1) in (2) gives

$$\frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

APPENDIX D
SUPPLEMENTARY DISCUSSION

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SUPPLEMENTARY DISCUSSION

In the discussion of results, it was suggested that yield effects in the metal of the interfaces contributed to the small initial deformations. An examination of one of the test runs for this effect is therefore in order.

Referring to Figure XIV, let us examine the stress situation in the C-1018 steel specimen for one of the initial deformations.

The maximum combined shearing stress in a cylinder loaded in this manner is given as follows: $(S_s)_{\max} = \sqrt{\frac{1}{4}(S_N)^2 + (S_T)^2}$
For S_N and S_T values, respectively, of 13200 and 1420 psi, the $(S_s)_{\max}$ is equal to 6750 psi.

Maximum shear theory states that yielding will occur when $(S_s)_{\max}$ equals the maximum shearing stress at yield point obtained from a tension test. The maximum shearing stress at yield point is one half yield stress for a tensile specimen.

Ryerson Steel Specifications for C-1018 steel give a yield value of 48000 psi.

Therefore maximum shear stress at yield point equals 24000 psi. The calculated stress for the specimen is well below this value; therefore yield will not occur in the bulk metal.

The normal stress value used in computing the combined shear stress was determined by using the cross-section area of the specimen, which at the interface is the apparent area of

EXPERIMENTAL RESULTS

In the apparatus at present, it was arranged that yield stress in the metal of the specimen was obtained by the usual tensile test, in a specimen of one of the best steel can stock in the market is used. Referring to Figure IV, let us examine the stress distribution in the C-100 steel specimen for one of the initial determinations.

The maximum measured elongation stress in a cylinder loaded in this manner is given by the formula $\sigma_{max} = \frac{1}{2}(\sigma_x + \sigma_y) + \frac{1}{2}(\sigma_x - \sigma_y) \sqrt{1 + \frac{4\tau_{xy}^2}{(\sigma_x - \sigma_y)^2}}$ for σ_x and σ_y values, respectively, of 12500 and 14500 psi, the τ_{xy} is equal to 6750 psi. Maximum stress theory states that yielding will occur when σ_{max} equals the maximum elongation stress of yield point of steel type 1 stainless steel. The maximum elongation stress of yield point is one half yield stress for a tensile specimen. Specimen steel specification for C-100 steel give a yield value of 18000 psi.

Therefore maximum stress theory of yield point predicts 18000 psi. The maximum stress for the specimen is 14500 psi. This value, therefore, yield will occur in the steel.

The above theory will hold in comparing the maximum stress theory with the maximum stress theory of the specimen, which at the initiation is the highest value of

contact. The real area of contact is less than this value due to the asperities in the metal of the interface.

Bowden and Tabor⁽⁴⁾ give the following relation for real area of contact:

$$A_r = \frac{F}{P_m}$$

P_m = mean pressure over area of contact

$$P_m = C \times S_{\text{yield}}$$

C has a value of 3 for material and surface finish used here.

$$P_m = 144000 \text{ psi for this case.}$$

$$A_{\text{real}} = 0.0014 \text{ in}^2, \text{ which is considerably less than the apparent value of } 0.0153 \text{ in}^2.$$

This would give a maximum combined shear stress in the contact surface considerably in excess of that required to initiate yield in the metal.

It is thus apparent that the stresses at the contact surface are more than sufficient to insure yield in the asperities in the metal interface. For very small values of deformation, the yield effects may thus be the sole contributing factor.

Now consider the stress values for the specimen under conditions encountered just prior to the advent of free sliding to S_N and S_T of 13200 and 4960 psi. The $(S_s)_{\text{max}}$ value is 8260 psi. Thus it is apparent that yield in the bulk material of the specimen does not occur, and all but the smallest displacements are due to slip between the two contact surfaces.

constant. The steel wire of constant is less than this value
due to the expansion in the metal of the interface.

London and Fisher⁽⁴⁾ give the following relation for steel

wire of constant α and β for the expansion of the wire in the

$$\frac{\Delta L}{L} = \alpha \Delta T + \beta \Delta T^2$$

where ΔL is the change in length, L is the original length, ΔT is the change in temperature, α is the coefficient of linear expansion, and β is the coefficient of quadratic expansion.

$$\frac{\Delta L}{L} = \alpha \Delta T + \beta \Delta T^2$$

For a value of β for material and surface finish
used here.

London and Fisher⁽⁴⁾ give the value of α for steel

$$\alpha = 6.5 \times 10^{-6} \text{ per } ^\circ\text{C}$$

and the expansion value of 6.5×10^{-6} in $^\circ\text{C}$.

This would give a maximum expansion value of 6.5×10^{-6} in the constant

value of α in terms of ΔT required to maintain
field in the metal.

It is then apparent that the expansion of the constant
value is not then sufficient to increase field in the range
field in the metal interface. For very small values of ΔT
field, the field effects may then be the only consideration.

London.

For constant the stress value for the specimen under

conditions mentioned just prior to the value of ΔT giving

$$\Delta L = \alpha \Delta T + \beta \Delta T^2$$

where ΔL is the change in length, L is the original length, ΔT is the change in temperature, α is the coefficient of linear expansion, and β is the coefficient of quadratic expansion.

of the specimen does not occur, and all the expansion is
transmitted to the slip between the two constant contacts.

APPENDIX E
ORIGINAL DATA

SPECIMEN NO.1

Material: C-1018 Steel

Control Specimen (without interface)

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>
	$F_N = 150 \text{ lb.}$	$F_N = 190.7 \text{ lb.}$	$F_N = 225.4 \text{ lb.}$	$F_N = 74.9 \text{ lb.}$	$F_N = 111.9 \text{ lb.}$
Q_A	ψ_s	ψ_s	ψ_s	ψ_s	ψ_s
150	44	44	49	40	45
300	92	89	96	101	97
450	139	143	146	-	144
600	189	197	193	-	196
750	239	243	-	-	-
900	285	296	292	-	-
1050	332	-	342	-	-
1200	-	-	391	-	-
1350	-	-	-	-	-

LONG TUNNELS

LONG TUNNELS (continued)

(continued results) southern section

$\frac{L_{eff}}{L_{tot}} = \frac{L_{eff}}{L_{tot}}$
 $\frac{L_{eff}}{L_{tot}} = \frac{L_{eff}}{L_{tot}}$
 $\frac{L_{eff}}{L_{tot}} = \frac{L_{eff}}{L_{tot}}$
 $\frac{L_{eff}}{L_{tot}} = \frac{L_{eff}}{L_{tot}}$
 $\frac{L_{eff}}{L_{tot}} = \frac{L_{eff}}{L_{tot}}$

$\frac{L_{eff}}{L_{tot}}$	$\frac{L_{eff}}{L_{tot}}$	$\frac{L_{eff}}{L_{tot}}$	$\frac{L_{eff}}{L_{tot}}$	$\frac{L_{eff}}{L_{tot}}$
0.1	0.1	0.1	0.1	0.1
0.2	0.2	0.2	0.2	0.2
0.3	0.3	0.3	0.3	0.3
0.4	0.4	0.4	0.4	0.4
0.5	0.5	0.5	0.5	0.5
0.6	0.6	0.6	0.6	0.6
0.7	0.7	0.7	0.7	0.7
0.8	0.8	0.8	0.8	0.8
0.9	0.9	0.9	0.9	0.9
1.0	1.0	1.0	1.0	1.0

0.1	0.1	0.1	0.1	0.1
0.2	0.2	0.2	0.2	0.2
0.3	0.3	0.3	0.3	0.3
0.4	0.4	0.4	0.4	0.4
0.5	0.5	0.5	0.5	0.5
0.6	0.6	0.6	0.6	0.6
0.7	0.7	0.7	0.7	0.7
0.8	0.8	0.8	0.8	0.8
0.9	0.9	0.9	0.9	0.9
1.0	1.0	1.0	1.0	1.0

SPECIMEN NO.2

Material: C-1018 Steel

Surface Finish:
As machined (lathe)Run No.1 $F_N = 251.2 \text{ lb.}$

Q_A	ψ_s
120	31
240	60
360	103
480	145
600	187
720	227
840	266
900	282
960	300
1080	342
1200	384
1320	433
1440	478

SPECIMEN NO.3

Material: C-1018 Steel

Surface Finish: No.1 Paper

Run No.2 $F_N = 251.2 \text{ lb.}$

Q_A	ψ_s	Q_A	ψ_s
120	38	120	36
240	80	240	74
360	123	360	110
480	168	480	144
600	203	600	183.5
720	241	720	226
840	-	840	268
900	-	900	-

Run No.3 $F_N = 201.29 \text{ lb.}$

Q_A	ψ_{sR}	Q_A	ψ_{sR}
120	--	120	--
240	--	240	--
360	--	360	--
480	--	480	--
600	--	600	--
720	5	720	5
840	7	840	7
900	--	900	--
960	17	960	17
1080	16	1080	16
1200	18	1200	18
1320	20	1320	20
1440	28	1440	28
1560	30	1560	30
1680	31	1680	31

1.2000

1994-2000

1-800-4-A-FLYER
1-800-4-6259

[illegible]

SPECIMEN NO.3 (continued)

<u>Run No.3 (cont.)</u>		<u>Run No.4</u>		<u>Run No.5</u>		<u>Run No.6</u>	
$F_N = 201.29 \text{ lb.}$		$F_N = 168.16 \text{ lb.}$		$F_N = 117.41 \text{ lb.}$		$F_N = 64.78 \text{ lb.}$	
Q_A	ψ_{SR}	Q_A	ψ_{SR}	Q_A	ψ_{SR}	Q_A	ψ_{SR}
2520	97	120	--	120	--	120	--
2640	124	240	--	240	15	240	--
2760	125	360	--	360	16	360	5
2880	156	480	--	480	13	480	16
3000	254	600	--	600	24	600	19
3120	257	720	2	720	19	720	317
3240	270	840	5	840	28	840	--
3360	319	960	8	960	29		
3480	--	1080	7	1080	29		
		1200	7	1200	41		
		1320	30	1320	58		
		1440	30	1440	75		
		1560	28	1560	109		
		1680	41	1680	--		
		1800	58				
		1920	67				
		2040	78				
		2160	142				
		2280	214				
		2400	--				

Chemical Equations

Reaction

Equation

Heat

(-7000) Heat

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

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at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

at 25°C, $\Delta H^\circ = 0$ kJ/mol

SPECIMEN NO.4

Material: C-1018 Steel

Surface Finish: 2/o Paper

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>	<u>Run No.6</u>
	$F_N = 81.75 \text{ lb.}$	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.3 \text{ lb.}$	$F_N = 200.3 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
Q_A	ψ_s	ψ_s	ψ_s	ψ_s	ψ_s	ψ_s
120	54	34	39	46	32	33
240	115	83	72	71	68	75
300	--	--	--	83	--	--
360		114	108	--	105	107
420	--	--	--	114	--	--
480			146	--	145	149
600			192	182	180	186
720			231	220	218	226
840			279	--	258	266
900			--	273	--	--
960				--	294	308
1020				320	--	--
1080				--	336	349
1140				372	--	--
1200				--	373	379
1320					413	416
1440					--	--

DATA SUMMARY

DATA SOURCE: Literature

DATA TYPE: Quantitative

Base unit: g^2 Fuel unit: g^2 Fuel unit: g^2 Fuel unit: g^2 Fuel unit: g^2 Fuel unit: g^2

00	00	00	00	00	00
01	01	01	01	01	01
02	02	02	02	02	02
03	03	03	03	03	03
04	04	04	04	04	04
05	05	05	05	05	05
06	06	06	06	06	06
07	07	07	07	07	07
08	08	08	08	08	08
09	09	09	09	09	09
10	10	10	10	10	10
11	11	11	11	11	11
12	12	12	12	12	12
13	13	13	13	13	13
14	14	14	14	14	14
15	15	15	15	15	15
16	16	16	16	16	16
17	17	17	17	17	17
18	18	18	18	18	18
19	19	19	19	19	19
20	20	20	20	20	20
21	21	21	21	21	21
22	22	22	22	22	22
23	23	23	23	23	23
24	24	24	24	24	24
25	25	25	25	25	25
26	26	26	26	26	26
27	27	27	27	27	27
28	28	28	28	28	28
29	29	29	29	29	29
30	30	30	30	30	30
31	31	31	31	31	31
32	32	32	32	32	32
33	33	33	33	33	33
34	34	34	34	34	34
35	35	35	35	35	35
36	36	36	36	36	36
37	37	37	37	37	37
38	38	38	38	38	38
39	39	39	39	39	39
40	40	40	40	40	40
41	41	41	41	41	41
42	42	42	42	42	42
43	43	43	43	43	43
44	44	44	44	44	44
45	45	45	45	45	45
46	46	46	46	46	46
47	47	47	47	47	47
48	48	48	48	48	48
49	49	49	49	49	49
50	50	50	50	50	50
51	51	51	51	51	51
52	52	52	52	52	52
53	53	53	53	53	53
54	54	54	54	54	54
55	55	55	55	55	55
56	56	56	56	56	56
57	57	57	57	57	57
58	58	58	58	58	58
59	59	59	59	59	59
60	60	60	60	60	60
61	61	61	61	61	61
62	62	62	62	62	62
63	63	63	63	63	63
64	64	64	64	64	64
65	65	65	65	65	65
66	66	66	66	66	66
67	67	67	67	67	67
68	68	68	68	68	68
69	69	69	69	69	69
70	70	70	70	70	70
71	71	71	71	71	71
72	72	72	72	72	72
73	73	73	73	73	73
74	74	74	74	74	74
75	75	75	75	75	75
76	76	76	76	76	76
77	77	77	77	77	77
78	78	78	78	78	78
79	79	79	79	79	79
80	80	80	80	80	80
81	81	81	81	81	81
82	82	82	82	82	82
83	83	83	83	83	83
84	84	84	84	84	84
85	85	85	85	85	85
86	86	86	86	86	86
87	87	87	87	87	87
88	88	88	88	88	88
89	89	89	89	89	89
90	90	90	90	90	90
91	91	91	91	91	91
92	92	92	92	92	92
93	93	93	93	93	93
94	94	94	94	94	94
95	95	95	95	95	95
96	96	96	96	96	96
97	97	97	97	97	97
98	98	98	98	98	98
99	99	99	99	99	99
100	100	100	100	100	100

SPECIMEN NO.5

Material: C-1018 Steel

Surface Finish: 4/o paper

<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>		<u>Run No.4</u>	
$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$		$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
Q_A	ψ_s	Q_A	ψ_s	Q_A	ψ_s	Q_A	ψ_s
120	33	120	39	120	30	120	--
150	--	150	--	150	--	150	43
240	73	240	82	240	74	240	--
300	--	300	--	300	--	300	91
360	108	360	126	360	117	360	--
420	--	420	--	420	--	420	--
450	--	450	--	450	--	450	141
480	153	480	167	480	151	480	--
600	188	600	201	600	191	600	190
720	228	720	232	720	230	720	--
750	--	750	--	750	--	750	241
840	318	840	280	840	269	840	--
900	--	900	--	900	--	900	291
960	--	960	321	960	310	960	--
		1020	--	1020	--	1020	--
		1050	--	1050	--	1050	332
		1080	385	1080	351	1080	--
		1140	--	1140	--	1140	--
				1200	390	1200	393
				1320	430	1320	--
				1350	--	1350	438
						1440	--
						1500	492
						1560	--

$$V_{\text{L}} = 110.7 \text{ m}^3, V_{\text{H}} = 107.1 \text{ m}^3, V_{\text{H}} = 90.2 \text{ m}^3, V_{\text{L}} = 97.7 \text{ m}^3$$
[illegible]

SPECIMEN NO.5 (continued)

<u>Run No.5</u>		<u>Run No.6</u>		<u>Run No.7</u>	
$F_N = 168.2 \text{ lb.}$		$F_N = 117.41 \text{ lb.}$		$F_N = 64.78 \text{ lb.}$	
Q_A	ψ_{SR}	ψ_{SR}	ψ_{SR}	ψ_{SR}	
120	--	--	--	--	
150	--	--	--	--	
240	--	--	--	16	
300	--	--	--	--	
360	--	3	--	16	
420	--	--	--	--	
450	--	--	--	--	
480	--	4	--	36	
600	--	19	--	64	
720	--	16	--	67	
750	--	--	--	--	
840	--	32	--	153	
900	--	--	--	--	
960	6	40	--	--	
1020	--	--	--	--	
1050	--	--	--	--	
1080	6	68	--	--	
1140	--	--	--	--	
1200	10	94	--	--	
1320	15	122	--	--	
1350	--	--	--	--	
1440	19	155	--	--	
1500	--	--	--	--	
1560	23	--	--	--	
1680	39	--	--	--	
1800	64	--	--	--	

5.04-015

100 = 100.00 % 100 = 100.00 % 100 = 100.00 %

SPECIMEN NO.6

Material: A-4140 Steel

Control Specimen (without interface)

<u>Run No.1</u>		<u>Run No.2</u>
$F_N = 251.2 \text{ lb.}$		$F_N = 200.2 \text{ lb.}$
Q_A	ψ_s	ψ_s
120	43	--
150	--	52
240	83	--
300	--	93
360	123	--
450	--	139
480	161	--
600	202	192
720	245	--
750	--	239
840	290	--
900	--	290
960	326	--
1020	--	
1080	363	
1200	400	

SECTION 3016

Material: A-110 Steel

Contract Agreement (without inspection)

Low Bid

Low Bid

at 2.005 = 1.0

at 2.113 = 1.0

1

1

1

1

1

100

1

1

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1

100

1

1

100

1

1

100

1

1

100

1

1

100

1

1

100

1

1

100

1

1

100

SPECIMEN NO. 7

Material: A-4140 Steel

Surface Finish: As machined

	<u>Run No. 1</u>	<u>Run No. 2</u>	<u>Run No. 3</u>	<u>Run No. 4</u>
	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.2 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
Q_A	ψ_s	ψ_s	ψ_s	ψ_s
120	32	38	38	42
150	--	--	--	51
240	74	78	--	--
300	--	--	108	119
360	123	130	--	--
450	--	--	--	--
480	169	187	--	--
600	219	236	214	211
720	--	294	270	--
750	--	--	--	--
840	--	--	--	--
900	--	--	356	344
960	--	--	--	--
1020				397

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λ	$\lambda - 0.001$	$\lambda - 0.002$	$\lambda - 0.003$	$\lambda - 0.004$
0.001	0.001	0.001	0.001	0.001
0.002	0.002	0.002	0.002	0.002
0.003	0.003	0.003	0.003	0.003
0.004	0.004	0.004	0.004	0.004
0.005	0.005	0.005	0.005	0.005
0.006	0.006	0.006	0.006	0.006
0.007	0.007	0.007	0.007	0.007
0.008	0.008	0.008	0.008	0.008
0.009	0.009	0.009	0.009	0.009
0.010	0.010	0.010	0.010	0.010
0.011	0.011	0.011	0.011	0.011
0.012	0.012	0.012	0.012	0.012
0.013	0.013	0.013	0.013	0.013
0.014	0.014	0.014	0.014	0.014
0.015	0.015	0.015	0.015	0.015
0.016	0.016	0.016	0.016	0.016
0.017	0.017	0.017	0.017	0.017
0.018	0.018	0.018	0.018	0.018
0.019	0.019	0.019	0.019	0.019
0.020	0.020	0.020	0.020	0.020
0.021	0.021	0.021	0.021	0.021
0.022	0.022	0.022	0.022	0.022
0.023	0.023	0.023	0.023	0.023
0.024	0.024	0.024	0.024	0.024
0.025	0.025	0.025	0.025	0.025
0.026	0.026	0.026	0.026	0.026
0.027	0.027	0.027	0.027	0.027
0.028	0.028	0.028	0.028	0.028
0.029	0.029	0.029	0.029	0.029
0.030	0.030	0.030	0.030	0.030
0.031	0.031	0.031	0.031	0.031
0.032	0.032	0.032	0.032	0.032
0.033	0.033	0.033	0.033	0.033
0.034	0.034	0.034	0.034	0.034
0.035	0.035	0.035	0.035	0.035
0.036	0.036	0.036	0.036	0.036
0.037	0.037	0.037	0.037	0.037
0.038	0.038	0.038	0.038	0.038
0.039	0.039	0.039	0.039	0.039
0.040	0.040	0.040	0.040	0.040
0.041	0.041	0.041	0.041	0.041
0.042	0.042	0.042	0.042	0.042
0.043	0.043	0.043	0.043	0.043
0.044	0.044	0.044	0.044	0.044
0.045	0.045	0.045	0.045	0.045
0.046	0.046	0.046	0.046	0.046
0.047	0.047	0.047	0.047	0.047
0.048	0.048	0.048	0.048	0.048
0.049	0.049	0.049	0.049	0.049
0.050	0.050	0.050	0.050	0.050

SPECIMEN NO.8

Material: A-4140 Steel

Surface Finish: No.1 Paper

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>
	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.2 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
Q_A	ψ_s	ψ_s	ψ_s	ψ_s
150	54	59	48	51
300	111	116	109	109
450	165	168	178	161
600	241	223	220	219
750	284	277	276	287
900	--	--	339	340
1050			--	393

9.07 EMISSIONS

Check only - 11/11/67
 report 1.00 - identify location

2000.000 2000.000 2000.000 2000.000
 at 2.500 $\times 10^4$ at 2.500 $\times 10^4$ at 2.500 $\times 10^4$ at 2.500 $\times 10^4$

λ^0	λ^0	λ^0	λ^0	λ^0
22	21	20	19	021
401	401	211	211	007
111	271	211	201	025
221	271	221	111	001
485	271	275	165	077
021	271	—	—	004
221	—	—	—	0201



SPECIMEN NO.8 (continued)

Run No.5

Run No.6

Run No.7

$F_N = 200 \text{ lb.}$

$F_N = 167 \text{ lb.}$

$F_N = 201.29 \text{ lb.}$

Q_A	ψ_s	ψ_s	Q_A	ψ_s
150	59	49	120	--
300	111	122	240	--
450	160	186	360	--
600	220	219	480	--
750	--	280	600	--
900		--	720	--
			840	--
			960	1
			1080	4
			1200	5
			1320	8
			1440	8
			1560	12
			1680	22
			1800	36
			1920	70
			2040	75
			2160	132
			2280	232
			2400	--

STANDARD GRADE

T. 20. 200		T. 20. 200		T. 20. 200	
T. 20. 200 = 2		T. 20. 200 = 2		T. 20. 200 = 2	
2	2	2	2	2	2
100	001	00	00	00	001
100	002	001	00	001	002
100	003	001	00	001	003
100	004	002	00	002	004
100	005	003	00	003	005
100	006	004	00	004	006
100	007	005	00	005	007
100	008	006	00	006	008
100	009	007	00	007	009
100	010	008	00	008	010
100	011	009	00	009	011
100	012	010	00	010	012
100	013	011	00	011	013
100	014	012	00	012	014
100	015	013	00	013	015
100	016	014	00	014	016
100	017	015	00	015	017
100	018	016	00	016	018
100	019	017	00	017	019
100	020	018	00	018	020
100	021	019	00	019	021
100	022	020	00	020	022
100	023	021	00	021	023
100	024	022	00	022	024
100	025	023	00	023	025
100	026	024	00	024	026
100	027	025	00	025	027
100	028	026	00	026	028
100	029	027	00	027	029
100	030	028	00	028	030
100	031	029	00	029	031
100	032	030	00	030	032
100	033	031	00	031	033
100	034	032	00	032	034
100	035	033	00	033	035
100	036	034	00	034	036
100	037	035	00	035	037
100	038	036	00	036	038
100	039	037	00	037	039
100	040	038	00	038	040
100	041	039	00	039	041
100	042	040	00	040	042
100	043	041	00	041	043
100	044	042	00	042	044
100	045	043	00	043	045
100	046	044	00	044	046
100	047	045	00	045	047
100	048	046	00	046	048
100	049	047	00	047	049
100	050	048	00	048	050
100	051	049	00	049	051
100	052	050	00	050	052
100	053	051	00	051	053
100	054	052	00	052	054
100	055	053	00	053	055
100	056	054	00	054	056
100	057	055	00	055	057
100	058	056	00	056	058
100	059	057	00	057	059
100	060	058	00	058	060
100	061	059	00	059	061
100	062	060	00	060	062
100	063	061	00	061	063
100	064	062	00	062	064
100	065	063	00	063	065
100	066	064	00	064	066
100	067	065	00	065	067
100	068	066	00	066	068
100	069	067	00	067	069
100	070	068	00	068	070
100	071	069	00	069	071
100	072	070	00	070	072
100	073	071	00	071	073
100	074	072	00	072	074
100	075	073	00	073	075
100	076	074	00	074	076
100	077	075	00	075	077
100	078	076	00	076	078
100	079	077	00	077	079
100	080	078	00	078	080
100	081	079	00	079	081
100	082	080	00	080	082
100	083	081	00	081	083
100	084	082	00	082	084
100	085	083	00	083	085
100	086	084	00	084	086
100	087	085	00	085	087
100	088	086	00	086	088
100	089	087	00	087	089
100	090	088	00	088	090
100	091	089	00	089	091
100	092	090	00	090	092
100	093	091	00	091	093
100	094	092	00	092	094
100	095	093	00	093	095
100	096	094	00	094	096
100	097	095	00	095	097
100	098	096	00	096	098
100	099	097	00	097	099
100	100	098	00	098	100

SPECIMEN NO.8 (continued)

Run No.8Run No.9Run No.10 $F_N = 168.16 \text{ lb.}$ $F_N = 117.41 \text{ lb.}$ $F_N = 64.78 \text{ lb.}$

Q_A	ψ_{sR}	ψ_{sR}	ψ_{sR}
120	--	--	--
240	--	--	15
360	--	12	73
480	--	22	772
600	10	57	--
720	35	91	
840	42	159	
960	79	283	
1080	85	--	
1200	82		
1320	99		
1440	115		
1560	135		
1680	209		
1800	225		
1920	239		
2040	266		
2160	475		
2280	--		

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Year	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	

SPECIMEN NO.10

Material: 2S Aluminum

Control Specimen: without interface

Q _A	Run No.1			Run No.2			Run No.3		
	F _N = 116 lb.			F _N = 16 lb.			F _N = 200 lb.		
	ψ_s	ψ_{SR}		ψ_s	ψ_s		ψ_s	ψ_s	
30	28	--		22	6		--	--	
60	60	--		50	5		53	7	
90	96	19		--	--		--	--	
120	119	19		100	4		101	1	
150	152	30		--	--		--	--	
180	181	26		135	21		--	--	
210	211	32		--	--		--	--	
240	250	39		221	30		229	29	
270	271	40		--	--		--	--	
300	296	42		272	31		274	29	
330	323	35		--	--		--	--	
360	360	44		336	35		337	46	
420	--	--		393	53		--	--	

SPECIMEN NO.11

Material: Copper

Control Specimen
(without interface)

<u>Run No.1</u>			<u>Run No.2</u>		<u>Run No.3</u>	
$F_N = 20 \text{ lb.}$			$F_N = 250 \text{ lb.}$		$F_N = 200 \text{ lb.}$	
Q_A	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	Q_A	ψ_{sR}
30	29	--	24	4	120	--
60	48	4	--	--	240	5
90	68	14	61	7	360	5
120	85	4	--	--	480	8
150	92	6	100	4	600	10
180	117	14	--	--	720	19
210	138	28	137	--	840	28
240	154	22	--	--	960	27
270	173	28	170	15	1080	25
300	191	37	--	--	1200	40
330	211	35	205	18	1320	50
360	228	37	--	--	1440	58
390	248	44	236	22	1560	71
420	261	48	--	--	1680	87
450	281	56	--	--	1800	84

EXHIBIT 11.11

Molecular Weight

Control Sample
(Molecular Weight)

Low MW		Low MW		Low MW	
MW = 100		MW = 100		MW = 100	
Wt %	Wt %	Wt %	Wt %	Wt %	Wt %
—	100	—	100	—	100
2	98	—	—	2	98
4	96	2	98	4	96
6	94	—	—	6	94
8	92	4	96	8	92
10	90	—	—	10	90
12	88	—	—	12	88
14	86	—	—	14	86
16	84	—	—	16	84
18	82	—	—	18	82
20	80	—	—	20	80
22	78	—	—	22	78
24	76	—	—	24	76
26	74	—	—	26	74
28	72	—	—	28	72
30	70	—	—	30	70
32	68	—	—	32	68
34	66	—	—	34	66
36	64	—	—	36	64
38	62	—	—	38	62
40	60	—	—	40	60
42	58	—	—	42	58
44	56	—	—	44	56
46	54	—	—	46	54
48	52	—	—	48	52
50	50	—	—	50	50

SPECIMEN NO.12

Material: A-4140 Steel

Surface Finish: 4/0 Paper

	<u>Run No.1</u>			<u>Run No.2</u>			<u>Run No.3</u>			<u>Run No.4</u>		
	$F_N = 31.875 \text{ lb.}$			$F_N = 53.38 \text{ lb.}$			$F_N = 117.41 \text{ lb.}$			$F_N = 168.2 \text{ lb.}$		
Q_A	ψ_S	ψ_{SR}		ψ_S	ψ_{SR}		ψ_S	ψ_{SR}		ψ_S	ψ_{SR}	
120	54	--		59	10		45	--		--	--	
150	--	--		--	--		53	--		58	--	
240	94	4		116	16		100	--		--	--	
300	--	--		--	--		122	--		105	--	
360	156	13		176	28		142	1		--	--	
450	--	--		--	--		180	--		164	--	
480	277	72		265	75		186	4		--	--	
600	--	--		365	225		228	16		231	14	
720				562	269		265	58		--	--	
750				--	--		270	--		283	10	
840							295	60		--	--	
960							345	76				
1080								92				
1200								100				
1320								149				
1440								183				
1560								267				
1680								659				

SPECIMEN NO.12 (continued)

	<u>Run No. 5</u>		<u>Run No. 6</u>		<u>Run No. 7</u>		<u>Run No. 8</u>	
	$F_N = 168.2 \text{ lb.}$		$F_N = 201.3 \text{ lb.}$		$F_N = 201.3 \text{ lb.}$		$F_N = 250 \text{ lb.}$	
Q_A	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}
150	54	--	60	--	59	--	69	--
300	113	--	119	--	113	--	123	--
450	162	--	178	--	174	--	174	--
600	225	8	237	3	236	--	238	--
750	273	14	302	17	303	12	294	12
900	387	172	371	23	350	12	351	12
1050	--	--	446	30	--	22	423	22

(continued) EL-08 8/28/2018

Sub. no.	Sub. no.	Sub. no.	Sub. no.	
at dec = 0°	at lat = 0°	at lat = 0°	at lat = 0°	
1001	1001	1001	1001	1001
1002	1002	1002	1002	1002
1003	1003	1003	1003	1003
1004	1004	1004	1004	1004
1005	1005	1005	1005	1005
1006	1006	1006	1006	1006
1007	1007	1007	1007	1007
1008	1008	1008	1008	1008
1009	1009	1009	1009	1009
1010	1010	1010	1010	1010
1011	1011	1011	1011	1011
1012	1012	1012	1012	1012
1013	1013	1013	1013	1013
1014	1014	1014	1014	1014
1015	1015	1015	1015	1015
1016	1016	1016	1016	1016
1017	1017	1017	1017	1017
1018	1018	1018	1018	1018
1019	1019	1019	1019	1019
1020	1020	1020	1020	1020

SPECIMEN NO.13

Material: Copper

Surface Finish: No.1 Paper

Q _A	<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>		<u>Run No.4</u>	
	$F_N = 168.2 \text{ lb.}$	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	$F_N = 201.3 \text{ lb.}$	ψ_s	ψ_{sR}
60		45	--	26	--	$F_N = 251 \text{ lb.}$	--	--
120		75	7	68	--		54	--
180		116	9	111	13		--	--
240		151	10	151	6		95	1
300		--	--	190	13		--	--
360				233	12		220	49
420				255	27		--	--
480				295	24		292	4
540				335	25		--	--
600				380	32		378	16
660				415	40		--	--
720				455	38		463	38
780				498	38		--	--
840				542	39		546	54

2000-2001		2001-2002		2002-2003		2003-2004		2004-2005		2005-2006		2006-2007		2007-2008		2008-2009		2009-2010		2010-2011		2011-2012		2012-2013		2013-2014		2014-2015		2015-2016		2016-2017		2017-2018		2018-2019		2019-2020		2020-2021		2021-2022		2022-2023		2023-2024		2024-2025		2025-2026		2026-2027		2027-2028		2028-2029		2029-2030		2030-2031		2031-2032		2032-2033		2033-2034		2034-2035		2035-2036		2036-2037		2037-2038		2038-2039		2039-2040		2040-2041		2041-2042		2042-2043		2043-2044		2044-2045		2045-2046		2046-2047		2047-2048		2048-2049		2049-2050		2050-2051		2051-2052		2052-2053		2053-2054		2054-2055		2055-2056		2056-2057		2057-2058		2058-2059		2059-2060		2060-2061		2061-2062		2062-2063		2063-2064		2064-2065		2065-2066		2066-2067		2067-2068		2068-2069		2069-2070		2070-2071		2071-2072		2072-2073		2073-2074		2074-2075		2075-2076		2076-2077		2077-2078		2078-2079		2079-2080		2080-2081		2081-2082		2082-2083		2083-2084		2084-2085		2085-2086		2086-2087		2087-2088		2088-2089		2089-2090		2090-2091		2091-2092		2092-2093		2093-2094		2094-2095		2095-2096		2096-2097		2097-2098		2098-2099		2099-2100		2100-2101		2101-2102		2102-2103		2103-2104		2104-2105		2105-2106		2106-2107		2107-2108		2108-2109		2109-2110		2110-2111		2111-2112		2112-2113		2113-2114		2114-2115		2115-2116		2116-2117		2117-2118		2118-2119		2119-2120		2120-2121		2121-2122		2122-2123		2123-2124		2124-2125		2125-2126		2126-2127		2127-2128		2128-2129		2129-2130		2130-2131		2131-2132		2132-2133		2133-2134		2134-2135		2135-2136		2136-2137		2137-2138		2138-2139		2139-2140		2140-2141		2141-2142		2142-2143		2143-2144		2144-2145		2145-2146		2146-2147		2147-2148		2148-2149		2149-2150		2150-2151		2151-2152		2152-2153		2153-2154		2154-2155		2155-2156		2156-2157		2157-2158		2158-2159		2159-2160		2160-2161		2161-2162		2162-2163		2163-2164		2164-2165		2165-2166		2166-2167		2167-2168		2168-2169		2169-2170		2170-2171		2171-2172		2172-2173		2173-2174		2174-2175		2175-2176		2176-2177		2177-2178		2178-2179		2179-2180		2180-2181		2181-2182		2182-2183		2183-2184		2184-2185		2185-2186		2186-2187		2187-2188		2188-2189		2189-2190		2190-2191		2191-2192		2192-2193		2193-2194		2194-2195		2195-2196		2196-2197		2197-2198		2198-2199		2199-2200		2200-2201		2201-2202		2202-2203		2203-2204		2204-2205		2205-2206		2206-2207		2207-2208		2208-2209		2209-2210		2210-2211		2211-2212		2212-2213		2213-2214		2214-2215		2215-2216		2216-2217		2217-2218		2218-2219		2219-2220		2220-2221		2221-2222		2222-2223		2223-2224		2224-2225		2225-2226		2226-2227		2227-2228		2228-2229		2229-2230		2230-2231		2231-2232		2232-2233		2233-2234		2234-2235		2235-2236		2236-2237		2237-2238		2238-2239		2239-2240		2240-2241		2241-2242		2242-2243		2243-2244		2244-2245		2245-2246		2246-2247		2247-2248		2248-2249		2249-2250		2250-2251		2251-2252		2252-2253		2253-2254		2254-2255		2255-2256		2256-2257		2257-2258		2258-2259		2259-2260		2260-2261		2261-2262		2262-2263		2263-2264		2264-2265		2265-2266		2266-2267		2267-2268		2268-2269		2269-2270		2270-2271		2271-2272		2272-2273		2273-2274		2274-2275		2275-2276		2276-2277		2277-2278		2278-2279		2279-2280		2280-2281		2281-2282		2282-2283		2283-2284		2284-2285		2285-2286		2286-2287		2287-2288		2288-2289		2289-2290		2290-2291		2291-2292		2292-2293		2293-2294		2294-2295		2295-2296		2296-2297		2297-2298		2298-2299		2299-2300		2300-2301		2301-2302		2302-2303		2303-2304		2304-2305		2305-2306		2306-2307		2307-2308		2308-2309		2309-2310		2310-2311		2311-2312		2312-2313		2313-2314		2314-2315		2315-2316		2316-2317		2317-2318		2318-2319		2319-2320		2320-2321		2321-2322		2322-2323		2323-2324		2324-2325		2325-2326		2326-2327		2327-2328		2328-2329		2329-2330		2330-2331		2331-2332		2332-2333		2333-2334		2334-2335		2335-2336		2336-2337		2337-2338		2338-2339		2339-2340		2340-2341		2341-2342		2342-2343		2343-2344		2344-2345		2345-2346		2346-2347		2347-2348		2348-2349		2349-2350		2350-2351		2351-2352		2352-2353		2353-2354		2354-2355		2355-2356		2356-2357		2357-2358		2358-2359		2359-2360		2360-2361		2361-2362		2362-2363		2363-2364		2364-2365		2365-2366		2366-2367		2367-2368		2368-2369		2369-2370		2370-2371		2371-2372		2372-2373		2373-2374		2374-2375		2375-2376		2376-2377		2377-2378		2378-2379		2379-2380		2380-2381		2381-2382		2382-2383		2383-2384		2384-2385		2385-2386		2386-2387		2387-2388		2388-2389		2389-2390		2390-2391		2391-2392		2392-2393		2393-2394		2394-2395		2395-2396		2396-2397		2397-2398		2398-2399		2399-2400		2400-2401		2401-2402		2402-2403		2403-2404		2404-2405		2405-2406		2406-2407		2407-2408		2408-2409		2409-2410		2410-2411		2411-2412		2412-2413		2413-2414		2414-2415		2415-2416		2416-2417		2417-2418		2418-2419		2419-2420		2420-2421		2421-2422		2422-2423		2423-2424		2424-2425		2425-2426		2426-2427		2427-2428		2428-2429		2429-2430		2430-2431		2431-2432		2432-2433		2433-2434		2434-2435		2435-2436		2436-2437		2437-2438		2438-2439		2439-2440		2440-2441		2441-2442		2442-2443		2443-2444		2444-2445		2445-2446		2446-2447		2447-2448		2448-2449		2449-2450		2450-2451		2451-2452		2452-2453		2453-2454		2454-2455		2455-2456		2456-2457		2457-2458		2458-2459		2459-2460		2460-2461		2461-2462		2462-2463		2463-2464		2464-2465		2465-2466		2466-2467		2467-2468		2468-2469		2469-2470		2470-2471		2471-2472		2472-2473		2473-2474		2474-2475		2475-2476		2476-2477		2477-2478		2478-2479		2479-2480		2480-2481		2481-2482		2482-2483		2483-2484		2484-2485		2485-2486		2486-2487		2487-2488		2488-2489		2489-2490		2490-2491		2491-2492		2492-2493		2493-2494		2494-2495		2495-2496		2496-2497		2497-2498		2498-2499		2499-2500		2500-2501		2501-2502		2502-2503		2503-2504		2504-2505		2505-2506		2506-2507		2507-2508		2508-2509		2509-2510		2510-2511		2511-2512		2512-2513		2513-2514		2514-2515		2515-2516		2516-2517		2517-2518		2518-2519		2519-2520		2520-2521		2521-2522		2522-2523		2523-2524		2524-2525		2525-2526		2526-2527		2527-2528		2528-2529		2529-2530		2530-2531		2531-2532		2532-2533		2533-2534		2534-2535		2535-2536		2536-2537		2537-2538		2538-2539		2539-2540		2540-2541		2541-2542		2542-2543		2543-2544		2544-2545		2545-2546		2546-2547		2547-2548		2548-2549		2549-2550		2550-2551		2551-2552		2552-2553		2553-2554		2554-2555		2555-2556		2556-2557		2557-2558		2558-2559		2559-2560		2560-2561		2561-2562		2562-2563		2563-2564		2564-2565		2565-2566		2566-2567		2567-2568		2568-2569		2569-2570		2570-2571		2571-2572		2572-2573		2573-2574		2574-2575		2575-2576		2576-2577		2577-2578		2578-2579		2579-2580		2580-2581		2581-2582		2582-2583		2583-2584		2584-2585		2585-2586		2586-2587		2587-2588		2588-2589		2589-2590		2590-2591		2591-2592		2592-2593		2593-2594		2594-2595		2595-2596		2596-2597		2597-2598		2598-2599		2599-2600		2600-2601		2601-2602		2602-2603		2603-2604		2604-2605		2605-2606		2606-2607		2607-2608		2608-2609		2609-2610		2610-2611		2611-2612		2612-2613		2613-2614		2614-2615		2615-2616		2616-2617		2617-2618		2618-2619		2619-2620		2620-2621		2621-2622		2622-2623		2623-2624		2624-2625		2625-2626		2626-2627		2627-2628		2628-2629		2629-2630		2630-2631		2631-2632		2632-2633		2633-2634		2634-2635		2635-2636		2636-2637		2637-2638		2638-2639		2639-2640		2640-2641		2641-2642		2642-2643		2643-2644		2644-2645		2645-2646		2646-2647		2647-2648		2648-2649		2649-2650		2650-2651		2651-2652		2652-2653		2653-2654		2654-2655		2655-2656		2656-2657		2657-2658		2658-2659		2659-2660		2660-2661		2661-2662		2662-2663		2663-2664		2664-2665		2665-2666		2666-2667		2667-2668		2668-2669		2669-2670		2670-2671		2671-2672		2672-2673		2673-2674		2674-2675		2675-2676		2676-2677		2677-2678		2678-2679		2679-2680		2680-2681		2681-2682		2682-2683		2683-2684		2684-2685		2685-2686		2686-2687		2687-2688		2688-2689		2689-2690		2690-2691		2691-2692		2692-2693		2693-2694		2694-2695		2695-2696		2696-2697		2697-2698		2698-2699		2699-2700		2700-2701		2701-2702		2702-2703		2703-2704		2704-2705		2705-2706		2706-2707		2707-2708		2708-2709		2709-2710		2710-2711		2711-2712		2712-2713		2713-2714		2714-2715		2715-2716		2716-2717		2717-2718		2718-2719		2719-2720		2720-2721		2721-2722		2722-2723		2723-2724		2724-2725		2725-2726		2726-2727		2727-2728	
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SPECIMEN NO.13 (continued)

<u>Run No.4</u>	<u>Run No.5</u>	<u>Run No.6</u>	<u>Run No.7</u>	<u>Run No.7</u>
$F_N = 64.78$ lb.	$F_N = 117.4$ lb.	$F_N = 168.16$ lb.	$F_N = 201.29$ lb.	$F_N = 201.29$ lb.
ψ_{SR}	ψ_{SR}	ψ_{SR}	ψ_{SR}	ψ_{SR}
120	--	--	--	120
240	2	8	--	240
360	11	7	8	360
480	13	5	15	480
600	16	8	13	600
720	26	17	19	720
840	--	42	28	840
960		63	40	960
1080		81	44	1080
1200		--	48	1200
1320			72	1320
1440			184	1440
1560			246	1560
1680			--	1680
				--

[illegible]

SPECIMEN NO.14

Material: Copper

Surface Finish: 2/0 Paper

Q_A	<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>	
	$F_N = 64.8 \text{ lb.}$		$F_N = 117.4 \text{ lb.}$		$F_N = 168.2 \text{ lb.}$	
	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}
120	73	--	66	--	64	--
240	152	16	136	5	133	--
360	237	26	219	16	205	--
480	341	44	304	33	269	--
600	464	289	393	57	353	5
720	--	--	501	90	431	13
840			521	124	501	15
960			--	294	586	21
1080				873	--	31
1200				--		34
1320						37
1440						64
						--

TABLE NO. 14

Material: Copper

Surface finish: 250 lgr

Run 1		Run 2		Run 3	
$V = 64.8 \text{ ft.}$		$V = 117.4 \text{ ft.}$		$V = 168.5 \text{ ft.}$	
P	V	P	V	P	V
120	77	—	66	—	84
140	102	10	116	—	111
160	127	20	119	—	120
180	141	30	104	—	126
200	164	40	107	0	131
220	—	50	101	11	137
240	—	60	101	21	141
260	—	70	—	31	146
280	—	80	—	41	—
300	—	90	—	51	—
320	—	100	—	61	—
340	—	110	—	71	—
360	—	120	—	81	—
380	—	130	—	91	—
400	—	140	—	101	—
420	—	150	—	111	—
440	—	160	—	121	—
460	—	170	—	131	—
480	—	180	—	141	—
500	—	190	—	151	—
520	—	200	—	161	—
540	—	210	—	171	—
560	—	220	—	181	—
580	—	230	—	191	—
600	—	240	—	201	—
620	—	250	—	211	—
640	—	260	—	221	—
660	—	270	—	231	—
680	—	280	—	241	—
700	—	290	—	251	—
720	—	300	—	261	—
740	—	310	—	271	—
760	—	320	—	281	—
780	—	330	—	291	—
800	—	340	—	301	—
820	—	350	—	311	—
840	—	360	—	321	—
860	—	370	—	331	—
880	—	380	—	341	—
900	—	390	—	351	—
920	—	400	—	361	—
940	—	410	—	371	—
960	—	420	—	381	—
980	—	430	—	391	—
1000	—	440	—	401	—
1020	—	450	—	411	—
1040	—	460	—	421	—
1060	—	470	—	431	—
1080	—	480	—	441	—
1100	—	490	—	451	—
1120	—	500	—	461	—
1140	—	510	—	471	—
1160	—	520	—	481	—
1180	—	530	—	491	—
1200	—	540	—	501	—
1220	—	550	—	511	—
1240	—	560	—	521	—
1260	—	570	—	531	—
1280	—	580	—	541	—
1300	—	590	—	551	—
1320	—	600	—	561	—
1340	—	610	—	571	—
1360	—	620	—	581	—
1380	—	630	—	591	—
1400	—	640	—	601	—
1420	—	650	—	611	—
1440	—	660	—	621	—
1460	—	670	—	631	—
1480	—	680	—	641	—
1500	—	690	—	651	—
1520	—	700	—	661	—
1540	—	710	—	671	—
1560	—	720	—	681	—
1580	—	730	—	691	—
1600	—	740	—	701	—
1620	—	750	—	711	—
1640	—	760	—	721	—
1660	—	770	—	731	—
1680	—	780	—	741	—
1700	—	790	—	751	—
1720	—	800	—	761	—
1740	—	810	—	771	—
1760	—	820	—	781	—
1780	—	830	—	791	—
1800	—	840	—	801	—
1820	—	850	—	811	—
1840	—	860	—	821	—
1860	—	870	—	831	—
1880	—	880	—	841	—
1900	—	890	—	851	—
1920	—	900	—	861	—
1940	—	910	—	871	—
1960	—	920	—	881	—
1980	—	930	—	891	—
2000	—	940	—	901	—
2020	—	950	—	911	—
2040	—	960	—	921	—
2060	—	970	—	931	—
2080	—	980	—	941	—
2100	—	990	—	951	—
2120	—	1000	—	961	—
2140	—	1010	—	971	—
2160	—	1020	—	981	—
2180	—	1030	—	991	—
2200	—	1040	—	1001	—
2220	—	1050	—	1011	—
2240	—	1060	—	1021	—
2260	—	1070	—	1031	—
2280	—	1080	—	1041	—
2300	—	1090	—	1051	—
2320	—	1100	—	1061	—
2340	—	1110	—	1071	—
2360	—	1120	—	1081	—
2380	—	1130	—	1091	—
2400	—	1140	—	1101	—
2420	—	1150	—	1111	—
2440	—	1160	—	1121	—
2460	—	1170	—	1131	—
2480	—	1180	—	1141	—
2500	—	1190	—	1151	—
2520	—	1200	—	1161	—
2540	—	1210	—	1171	—
2560	—	1220	—	1181	—
2580	—	1230	—	1191	—
2600	—	1240	—	1201	—
2620	—	1250	—	1211	—
2640	—	1260	—	1221	—
2660	—	1270	—	1231	—
2680	—	1280	—	1241	—
2700	—	1290	—	1251	—
2720	—	1300	—	1261	—
2740	—	1310	—	1271	—
2760	—	1320	—	1281	—
2780	—	1330	—	1291	—
2800	—	1340	—	1301	—
2820	—	1350	—	1311	—
2840	—	1360	—	1321	—
2860	—	1370	—	1331	—
2880	—	1380	—	1341	—
2900	—	1390	—	1351	—
2920	—	1400	—	1361	—
2940	—	1410	—	1371	—
2960	—	1420	—	1381	—
2980	—	1430	—	1391	—
3000	—	1440	—	1401	—
3020	—	1450	—	1411	—
3040	—	1460	—	1421	—
3060	—	1470	—	1431	—
3080	—	1480	—	1441	—
3100	—	1490	—	1451	—
3120	—	1500	—	1461	—
3140	—	1510	—	1471	—
3160	—	1520	—	1481	—
3180	—	1530	—	1491	—
3200	—	1540	—	1501	—
3220	—	1550	—	1511	—
3240	—	1560	—	1521	—
3260	—	1570	—	1531	—
3280	—	1580	—	1541	—
3300	—	1590	—	1551	—
3320	—	1600	—	1561	—
3340	—	1610	—	1571	—
3360	—	1620	—	1581	—
3380	—	1630	—	1591	—
3400	—	1640	—	1601	—
3420	—	1650	—	1611	—
3440	—	1660	—	1621	—
3460	—	1670	—	1631	—
3480	—	1680	—	1641	—
3500	—	1690	—	1651	—
3520	—	1700	—	1661	—
3540	—	1710	—	1671	—
3560	—	1720	—	1681	—
3580	—	1730	—	1691	—
3600	—	1740	—	1701	—
3620	—	1750	—	1711	—
3640	—	1760	—	1721	—
3660	—	1770	—	1731	—
3680	—	1780	—	1741	—
3700	—	1790	—	1751	—
3720	—	1800	—	1761	—
3740	—	1810	—	1771	—
3760	—	1820	—	1781	—
3780	—	1830	—	1791	—
3800	—	1840	—	1801	—
3820	—	1850	—	1811	—
3840	—	1860	—	1821	—
3860	—	1870	—	1831	—
3880	—	1880	—	1841	—
3900	—	1890	—	1851	—
3920	—	1900	—	1861	—
3940	—	1910	—	1871	—
3960	—	1920	—	1881	—
3980	—	1930	—	1891	—
4000	—	1940	—	1901	—
4020	—	1950	—	1911	—
4040	—	1960	—	1921	—
4060	—	1970	—	1931	—
4080	—	1980	—	1941	—
4100	—	1990	—	1951	—
4120	—	2000	—	1961	—
4140	—	2010	—	1971	—
4160	—	2020	—	1981	—
4180	—	2030	—	1991	—
4200	—	2040	—	2001	—
4220	—	2050	—	2011	—
4240	—	2060	—	2021	—
4260	—	2070	—	2031	—
4280	—	2080	—	2041	—
4300	—	2090	—	2051	—
4320	—	2100	—	2061	—
4340	—	2110	—	2071	—
4360	—	2120	—	2081	—
4380	—	2130	—	2091	—
4400	—	2140	—	2101	—
4420	—	2150	—	2111	—
4440	—	2160	—	2121	—
4460	—	2170	—	2131	—
4480	—	2180	—	2141	—
4500	—	2190	—	2151	—
4520	—	2200	—	2161	—
4540	—	2210	—	2171	—
4560	—	2220	—	2181	—
4580	—	2230	—	2191	—
4600	—	2240	—	2201	—
4620	—	2250	—	2211	—
4640	—	2260	—	2221	—
4660	—	2270	—	2231	—
4680	—	2280	—	2241	—
4700	—	2290	—	2251	—
4720	—	2300	—	2261	—
4740	—	2310	—	2271	—
4760	—	2320	—	2281	—
4780	—	2330	—	2291	—
4800	—	2340	—	2301	—
4820	—	2350	—	2311	—
4840	—	2360	—	2321	—
4860	—	2370	—	2331	—
4880	—	2380	—		

SPECIMEN NO.14 (continued)

Run No.4 $F_N = 201.3 \text{ lb.}$

Q_A	ψ_B	ψ_{BR}
120	68	--
240	148	16
360	224	23
480	303	38
600	374	48
720	468	63
840	550	67
960	630	79
1080	--	88
1200		95
1320		119
1440		135
1560		178
1680		194
1800		218
1920		258
2040		--

Run No.5 $F_N = 231.68 \text{ lb.}$

Q_A	ψ_B	ψ_{BR}
120	77	--
240	113	14
360	228	28
480	309	37
600	383	43
720	465	54
840	543	66
960	633	85
1080	--	84
1200		96
1320		117
1440		118
1560		139
1680		155
1800		165
1920		180
2040		203
2160		235
2280		261
2400		292
2520		--

(Received 24 June 1997; accepted 12 July 1997)

Year	Age	Sex	Year	Age	Sex
1900	10	M	1900	10	M
1901	11	F	1901	11	F
1902	12	M	1902	12	M
1903	13	F	1903	13	F
1904	14	M	1904	14	M
1905	15	F	1905	15	F
1906	16	M	1906	16	M
1907	17	F	1907	17	F
1908	18	M	1908	18	M
1909	19	F	1909	19	F
1910	20	M	1910	20	M
1911	21	F	1911	21	F
1912	22	M	1912	22	M
1913	23	F	1913	23	F
1914	24	M	1914	24	M
1915	25	F	1915	25	F
1916	26	M	1916	26	M
1917	27	F	1917	27	F
1918	28	M	1918	28	M
1919	29	F	1919	29	F
1920	30	M	1920	30	M
1921	31	F	1921	31	F
1922	32	M	1922	32	M
1923	33	F	1923	33	F
1924	34	M	1924	34	M
1925	35	F	1925	35	F
1926	36	M	1926	36	M
1927	37	F	1927	37	F
1928	38	M	1928	38	M
1929	39	F	1929	39	F
1930	40	M	1930	40	M
1931	41	F	1931	41	F
1932	42	M	1932	42	M
1933	43	F	1933	43	F
1934	44	M	1934	44	M
1935	45	F	1935	45	F
1936	46	M	1936	46	M
1937	47	F	1937	47	F
1938	48	M	1938	48	M
1939	49	F	1939	49	F
1940	50	M	1940	50	M
1941	51	F	1941	51	F
1942	52	M	1942	52	M
1943	53	F	1943	53	F
1944	54	M	1944	54	M
1945	55	F	1945	55	F
1946	56	M	1946	56	M
1947	57	F	1947	57	F
1948	58	M	1948	58	M
1949	59	F	1949	59	F
1950	60	M	1950	60	M
1951	61	F	1951	61	F
1952	62	M	1952	62	M
1953	63	F	1953	63	F
1954	64	M	1954	64	M
1955	65	F	1955	65	F
1956	66	M	1956	66	M
1957	67	F	1957	67	F
1958	68	M	1958	68	M
1959	69	F	1959	69	F
1960	70	M	1960	70	M
1961	71	F	1961	71	F
1962	72	M	1962	72	M
1963	73	F	1963	73	F
1964	74	M	1964	74	M
1965	75	F	1965	75	F
1966	76	M	1966	76	M
1967	77	F	1967	77	F
1968	78	M	1968	78	M
1969	79	F	1969	79	F
1970	80	M	1970	80	M
1971	81	F	1971	81	F
1972	82	M	1972	82	M
1973	83	F	1973	83	F
1974	84	M	1974	84	M
1975	85	F	1975	85	F
1976	86	M	1976	86	M
1977	87	F	1977	87	F
1978	88	M	1978	88	M
1979	89	F	1979	89	F
1980	90	M	1980	90	M
1981	91	F	1981	91	F
1982	92	M	1982	92	M
1983	93	F	1983	93	F
1984	94	M	1984	94	M
1985	95	F	1985	95	F

SPECIMEN NO.15

Material: Copper

Surface Finish: 4/0 Paper

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>
	$F_N = 201.3 \text{ lb.}$	$F_N = 168.2 \text{ lb.}$	$F_N = 117.4 \text{ lb.}$	$F_N = 168.2 \text{ lb.}$	$F_N = 117.4 \text{ lb.}$
C_A	ψ_s	ψ_{SR}	ψ_{SR}	ψ_{SR}	ψ_{SR}
120	70	--	--	--	7
240	143	--	--	9	28
360	207	6	--	13	52
480	288	--	2	17	122
600	365	14	11	30	--
720	--	1	13	36	
840		5	20	67	
960		3	--	99	
1080		6		--	
1200		11	17		
1320		22	19		
1440		31	20		
1560		40	27		
1680		57	54		
1800		64	--		
1920		--			

[illegible]

24.000 6.000 2.000

SPECIMEN NO.15 (continued)

Material: Copper

Surface Finish: 4/0 Paper

Run No.6 $F_N = 64.8$ lb.Run No.7 $F_N = 64.8$ lb.

Q_A	ψ_{SR}	ψ_{SR}
120	-9	8
240	2	21
360	33	82
480	--	741
600		--

SPECIMEN NO.16

Material: 2S Aluminum

Surface Finish: No.1 Paper

Run No.1 $F_N = 168.2$ lb.Run No.2 $F_N = 201.3$ lb.

Q_A	ψ_S	ψ_{SR}	ψ_S	ψ_{SR}
12	16	4	--	--
30	36	12	33	--
60	73	12	52	--
90	93	24	90	10
120	126	28	112	12
150	163	37	143	16
180	182	52	172	12
210	215	61	194	18
240	246	55	229	22
270	273	63	260	16
300	301	66	283	32
330	343	71	--	--
360	368	73		
390	395	83		
420	420	86		

01.04.1998

NUMBER NO. 12 (continued)

Wojciech J. G. Turek

Издатель: Юридический

[illegible]

1997-01-16 10:10:10

$$\text{d}I_{\text{Coul}} = \gamma^2 \cdot \text{d}I_{\text{SAB}} = \frac{1}{16}$$
$$-0.13 \pm 0.04$$

THE

1951

2000

35

DEFINITION OF SYMBOLS

- A = area (square inches)
 D_i = inside diameter of specimen (inches)
 D_o = outside diameter of specimen (inches)
 E = modulus of elasticity (Young's modulus) (lb./in^2)
 $E_s = G$ = modulus of rigidity (shearing modulus) (lb/in^2)
 F_N = force normal to interface (normal load on specimen)
 (pounds or kilograms)
 L = gage length or length along specimen between indicator
 arms (inches)
 Q_A = applied torque (gram inches)
 R = radius of indicator arm (inches)
 r_m = mean radius of specimen (inches)
 S_N = normal stress at interface (lb/in^2)
 s_n = normal stress at interface (kg/cm^2)
 S_p = principal stress in specimen (lb/in^2)
 S_s = combined shear stress in specimen (lb/in^2)
 S_T = maximum tangential stress in interface due
 to applied torque (lb/in^2)
 s_t = maximum tangential stress in interface (kg/cm^2)
 T_A = torque applied to specimen (lb. inches)
 ψ_c = calculated angle of twist for specimen
 without interface (minutes of arc)
 ψ_o = observed angle of twist in specimen (minutes of arc)
 ψ_R = residual angle of twist in specimen (minutes of arc)
 ψ_s = observed angle of twist in specimen (micrometer drum units)
 ψ_{sR} = residual angle of twist in specimen (micrometer drum units)
 θ_R = apparent slip at interface (centimeters)

[illegible]

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